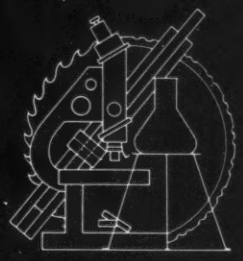
Journal of the Forest Products Research Society



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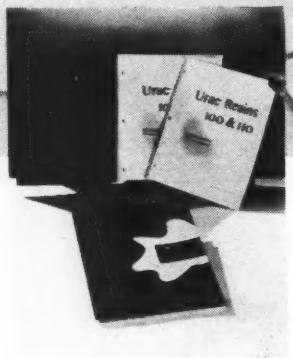

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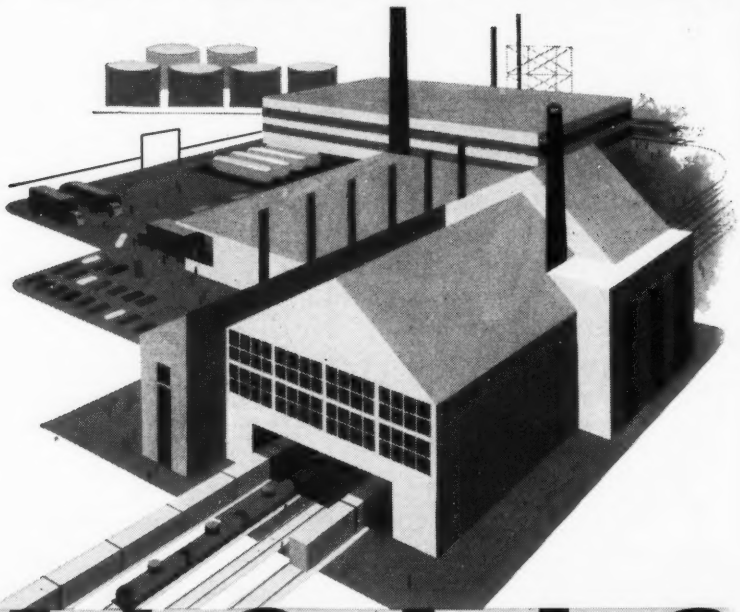

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RESEARCH ★ DEVELOPMENT ★ PRODUCTION ★ UTILIZATION ★ DISTRIBUTION

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The Hardboard Industry in the United States[1]

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Engineer, Forest Products Laboratory,[2] Forest Service U. S. Department of Agriculture

RARELY DOES A MONTH PASS but that some new hardboard mill starts to investigate the possibilities of such production, or ground is broken for the construction of the physical plant for such production. After so many years when the hardboard field was dominated by one producer, this sudden awakening to the potentialities of hardboard production creates many interesting and stimulating problems. This article discusses some of the problems resulting from the present mushrooming growth in the hardboard industry.

The following tabulation presents an estimate of the productive capacity for hardboards in the United States in 1948 as compared to what can be expected by the end of 1953. What the projected capacity will be more than a year hence is anybody's guess.

Year	Number of mills producing hardboard	Daily productive capacity	
		Tons	Square feet[1]
1948	3	935	2,500,000
1953	16	2,100	5,800,000

[1] Equivalent 1/8-inch-thick board.

Problems Introduced by Increased Production

Most of the new hardboard mills are being established in the far western states, and, since major markets are east of the Rocky Mountains, further problems are introduced by the source of supply being distant from the major markets. Among the problems introduced by the large increase are the following.

(1) Present markets have been established based on present production. Production is channeled to the various uses through well-established sales organizations. Increasing quantities of new products are finding their way into the present well-established markets. This disrupts the market, and it will become more difficult, as production continues to increase, to absorb the new volume. How much additional production can be absorbed without considerable market development before there is an over-all softening of the market is a matter of conjecture, but it continues to remain a possibility.

(2) Present uses for hardboard are based largely on experience with one producer's products. The consumer has found that he can use a certain product for a given use. For many of the uses he has a considerable margin, that is, the product he has been using is more than adequate for his particular use. Buying confidence has been built up, and certainly the consumer has every right to expect any product that he buys to perform favorably with other products having the same cost. This points out the desirability and necessity for the standardization and the equality of competitive products. Products of lower quality and cost should be available for uses that do not require the properties associated with products usually used.

(3) Because present uses for hardboards can only absorb so much production, it becomes increasingly important that new uses for these products be developed. It is the responsibility of everyone connected with production, sales, and utilization of forest products to stimulate the development of new and additional uses for hardboards. This country has the material and ability to produce many times as much hardboards as it is now doing, and the ultimate in production will be dictated by the volume that can be used.

(4) The consumer needs to be educated as to where hardboards can be used successfully. He needs to know where he can use hardboard and where he should not use it, and what is the proper grade and quality for a given use. Proper use will continue to build confidence and to increase the volume that can be produced and sold. Misuse will hurt as much as proper use will help.

(5) Production of hardboards in the past has been concentrated in the South, and the new production is developing in the far western states. Both of these sources of supply are relatively distant from population and manufacturing centers. Freight tariffs have a substantial influence on final market price. Favorable freight rates, particularly as they compare with those for competitive products, must be maintained in order to maintain markets. At lease two brands of hardboard produced in Canada and several produced in the Scandinavian countries are being sold in this country in competition with hardboards produced locally. The duty on these products is of concern to those manufacturing and selling hardboard.

(6) Specifications for procurement have been principally based on the quality of prior production, which involved two principal products, a standard and a treated grade. The new processes yield products having distinct and new qualities. Hardboards are manufactured products and as such, within limits, can be tailored for typical uses. Procurement specifications are in need of revision so that the greater range in material being produced will be covered by specification. Savings can be effected, for example, by the Government on procurement of hardboard products for uses that do not require all of the high strength and physical properties covered in the present Federal Specifications.

(7) Test procedures are needed for properly evaluating different hardboard products. The American Society for Testing Materials Tentative Method of Test for Evaluating the

[1] Presented at meeting of Forest Products Research Society, Carolinas–Chesapeake Section, Raleigh, N. C., Nov. 7, 1952.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Properties of Fiber Building Boards, Designation D1037–52T, presents test procedures for this purpose, but they can be considered as incomplete. Many additional test procedures are needed. Also, increased use of the tests will indicate certain desirable improvements. Tests are needed to compare the properties of different hardboard products, to measure the quality required for a given use, for use in determining limit values for procurement specifications, and for determining the engineering properties of hardboards. Hardboards can be and should be considered as engineering materials. The test procedures used to determine a given engineering property have an effect on the value obtained. To minimize differences between different evaluators, test procedures should be as near uniform as possible. Also, test procedures for hardboards should be such that results can be compared with test results from competitive and alternate materials.

(8) A uniform system of terms relating to hardboards is needed. Proper nomenclature and definitions, so that all concerned are talking and writing the same language, are of paramount importance. For example, the terms "treated, tempered, exterior, and water-resistant" are used to indicate that a hardboard has received special treatment for added water resistance and increased strength.

Hardboard, Defined and Described

To some people, a hardboard is a screen-backed, wet-felted board with a specific gravity of 0.9 to 1.1. That describes the principal products of the largest hardboard producer and the one who has pioneered production in the United States. It is a very restrictive definition. To others, a hardboard is any board product that is not a softboard and includes all of the fiberboard products that have a specific gravity greater than about 0.4 (the greatest density that can reasonably be made on a cylinder or Fourdrinier machine without auxiliary hot pressing). This includes most wallboards and is admittedly a very broad definition.

Hardboard, for the purposes here, is defined as being a fiber-board composed of vegetable fiber and natural and added binders, formed in a mat and pressed in the presence of heat so that the resulting product is an essentially homogeneous sheet. A further restriction is made that the product shall have a specific gravity of at least 0.8 to qualify as a hardboard.

No restriction is placed on method of manufacture or whether the board be primarily fiber or particle. The essentially fibrous boards constitute the bulk of hardboards and include the boards made by fiberizing wood substance by essentially pulping procedures and forming the boards either by the conventional wet-felting or by air-felting of dry or partially dry fiber. The particle boards are the resin-bonded boards manufactured from sawdust planer shavings, and from other millwork waste, which are essentially discrete particles rather than fibers or fiber bundles. They represent a small part of the volume but reflect an important trend.

The question naturally arises as to why the resin-bonded particle boards are considered with the conventional wet-felted boards when they appear to be so completely different. The primary bond in the instance of the wet- or air-felted hardboard involves a combination of lignin and the interfelting of the fibers, while the bond in the particle boards is almost wholely due to the added resin adhesive. It is true that the particle boards could be divorced from consideration with the fibrous boards, if, and that is a big word, all products could clearly be designated as being either fibrous or particle in nature. There are some products in the development and production stage that are neither particle nor fibrous in nature. They are a combination of both. Thus, it is possible to make boards with different combinations of particle and fiber, and it appears best to consider all of them as hardboards because the particle boards have so many of the same uses as do the purely fibrous ones.

Hardboard is just one of a group of fiberboards. The following classification system by density may be used to separate the different classes of fiberboards to show how the hardboards fit into the over-all picture.

Material	Specific Gravity
Semi-rigid insulation board	0.02 to 0.15
Rigid insulation board	.15 to .40
Intermediate density board	.40 to .80
Hardboard, untreated or treated	.80 to 1.15
Super hardboards	1.35 to 1.45

Classification of fiberboards by density is not an ideal one, particularly when there is a considerable overlap in both properties and uses. When details of manufacture and everything else are considered, a classification by density can be used with better success than limitations based on thickness, strength, or some other mechanical property.

Hardboards are essentially homogeneous sheet materials usually manufactured in thickness of $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ inch and in panels as large as 4 by 16 feet. The natural color of hardboards may vary with different products from a light tan to a dark brown, depending on the manufacturing method, the type of raw material, and additives used. Coloring pigment or dye may be added during manufacture to produce a colored or black board.

Hardboard may have both surfaces smooth (smooth two sides), or, as is necessary when wet pressing methods are used, the back of the board may be imprinted by the screen, which is used during pressing to allow steam to escape from between the platens of the press. This is known as screen-backed board. The surface of hardboards may be embossed to simulate the surface of leather, ceramic tile, or some other material for certain specialty uses. This is usually done by postforming.

They are dense, hard, relatively stiff, and may have synthetic resins or drying oils added during manufacture to give greater strength, stability, and water resistance for exterior or other severe use. Hardboards are manufactured in a standard or interior grade, and in a treated or exterior grade with limitations in use similar to those for softwood plywood.

Basic Manufacturing Processes

The conventional process for making hardboards may be described as being a wet-felting process. Wood chips are reduced to a high yield pulp by some defiberizing procedure and, after washing, are conveyed in a slurry and deposited and felted on a screen in the desired wet thickness. After drainage and added suction or squeezing to remove as much excess water as possible, the wet mat is transferred to another screen. The mat is then compressed and dried in a hot press. Some hydrolysis occurs during pressing, and, because of the moisture and heat present during this operation, the lignin present is plasticized so that the fibers are bonded together. Because the excess moisture must escape from between the platens during the pressing operation, it is necessary to produce a screen-backed board.

A variation of the conventional process is to form the wet mat as before but to dry it before the pressing operation. This drying is usually performed in continuous driers such as are used in making insulation board. The dried mat is then compressed at high temperature in the hot press, and the resultant hardboard has two smooth faces. In fact, when this variation is used in manufacture, virtually, an insulation board is produced that later is made into a hardboard by hot pressing. An advantage in this manufacturing procedure, in addition to

producing a board with two smooth faces, is a much shorter pressing cycle.

A different type of manufacturing process is being used in some of the production developments in the Pacific Northwest. This, for the want of a more descriptive title, has been called an air-felting, or dry process. The outstanding development in recent years has been that of the techniques by which fiberboard mats may be formed from air suspensions rather than water. In this process, chips are defiberized as in the wet process. Fibers, after addition of small amounts of resin, are either conveyed mechanically or by air (instead of in a slurry) and deposited and felted on an endless belt or screen by some type of special former. The dry mat is then compressed into a hardboard in the hot press. If the moisture content of the fibers is kept low (sometimes they are dried before felting), a smooth two-faced board may be produced. Principal advantages for this process appear to be that hardboard can be produced in areas where there is not a source of fresh water in sufficient quantity to operate a conventional hardboard plant; it eliminates the possibility of pollution in streams or bodies of water where pollution may be critical; and it permits use of relatively short pressing cycles because moisture contents in the boards at pressing are low.

Particle boards are formed dry with the fractions of wood being essentially slivers or granules bonded together by glues. The fractions are produced by mechanical means from millwork waste, veneer clippings, or other sources. The desired size and gradation of particles are produced by hammer-milling or other types of grinding and cutting, after which the particles are coated with an adhesive and boards are formed mechanically and the resin is cured in a hot press. In this type of hardboard the end product is only as good as the bond and the mechanical equipment used for forming. Particle size and shape and resin distribution are of utmost importance. Improvements are occurring continually that improve the quality and increase the use of these products.

Tempering or treating with drying oils to increase the water resistance and strength are usually done as the final operation. Boards are dipped in the oil and then baked in ovens or kilns. Baking distributes the oil throughout the board and stabilizes it.

Uses for Hardboard

The uses for hardboards are diverse, with about one-half of the production being subjected to some further remanufacture before reaching the ultimate consumer; hence it can be said that this portion of production is for the industrial market while the remainder is for the consumer market. Material for the consumer market finds an outlet through retail lumber yards in 4- by 4-, 4- by 6-, 4- by 8-, 4- by 10-, 4- by 12-, and 4- by 16-foot panels. Common thicknesses are $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ inch.

Generally, hardboard has many of the same uses as the thinner thicknesses of plywood except where weight is of paramount importance, such as in packaging. In some other uses hardboards have uses where plywood is not a strong competitor.

Most of the present uses for hardboards have service records that clearly demonstrate the advantages of the material. In the furniture industry hardboards are used for mirror backs, drawer bottoms, desk tops, and insert panels and backs for chests of drawers and wardrobes. In the appliance field hardboards find an outlet in backs for radios and television sets and as liners and backs for refrigerators and freezers. They are used extensively in templets and jigs for manufacturing operations, and some of the special dense hardboards are used to a limited extent in dies and forms for working metals and for electrical-control panels. In household furnishings, they are used for facings for flush doors, and as backs, doors, and counter tops for kitchen cabinets and storage units. In the transportation field increasing amounts of hardboards are being used for panels, liners, and partitions in truck, bus, trailer, and Pullman car bodies.

In buildings and houses hardboard may be used for paneling, counter faces and tops, facing for concrete forms, linoleum, underlayment, exterior wall covering, and, to a limited extent, as floor surfacing. They are used considerably in advertising displays, signs, and toys.

Among the newer and projected uses for hardboard that hold prospects for using increasingly large amounts of hardboard are (1) facing for plywood, (2) base for plastic overlays, (3) crossband material for veneered furniture, and (4) stress-cover material for homes and other small buildings. Several plywood mills are presently manufacturing hardboard-faced plywood. When Douglas-fir crossbands and cores are used, the composite is known as Plyron and it conforms to standards set up and maintained by the Douglas Fir Plywood Association. Other softwoods also are being used. Hardboards provide an excellent base for the thin, highly decorative plastic overlays that are used so extensively for counter, table, and bar tops in homes, restaurants, stores, and taverns. Hardboards have been used to a limited extent as stress-cover material for prefabricated house panels. As the prefabricated housing industry grows, larger amounts can be used.

Specifications for Hardboards

Existing standards for hardboards are few and not anywhere near so extensive as the number and diversity of products warrants. The principal existing American specification for hardboard is Federal Specification LLL–F–311, Fiberboard, Hard Pressed, Structural, which has not been revised since 1939. This specification, which is used for Government procurement of hardboards, covers but two classes of board, (1) untreated and (2) treated, with a specific gravity of at least 0.96 and having a bending strength of 6,000 pounds per square inch for the untreated or 10,000 pounds per square inch for the treated board. Hardboards are manufactured materials and, within limits, can be tailored to meet a given use requirement. One manufacturer makes as many as 20 different variations to satisfy the different uses for his product. With this range, it appears desirable to have more of the possible variations covered by specifications.

There is no general commercial standard for hardboard. A recent standard, Commercial Standard 176–51, Prefinished Wall Panels, sponsored by the Predecorated Wallboard Council, covers requirements for predecorative wall-covering material of the embossed hardboard type. The hardboard industry is aware of the need for commercial standards for its products. The recently formed hardboard trade association has started work that will probably culminate in standards for more of the products of the industry.

Methods of test for evaluating the different physical strength properties of hardboard are of utmost importance. The method of test used to obtain a given property has an effect on the values obtained, and uniform, accurate evaluation procedures must precede the establishing of minimum or maximum specification values. The American Society for Testing Materials Method D1037, Methods of Test for Evaluating the Properties of Fiber Building Boards, presents testing procedures apparently most applicable for hardboards. These test methods are intended for evaluating the properties of all fiberboards—not just the hardboards. All desirable test procedures are not included; there is need for development of additional ones as well as for improvement of present proce-

dures. Among these needed test procedures deemed most important are those for impact resistance and toughness, compression, gluability, machinability, fire resistance, smoothness, and shear resistance.

The importance of standardization of test procedures on an international basis has been recognized. The committee on Mechanical Wood Technology of the Food and Agriculture Organization of the United Nations has been working on this problem during the past three years. It recently reached an agreement on test procedures for fiberboard products that follows American Society for Testing Materials method D1037 and is in general agreement with it.

Properties of Hardboards

The properties of different hardboards vary to a considerable extent, and this is understandable when all of the different manufacturing procedures, raw materials, and treatments, as well as intended uses, are considered. The following tabulation is included in this article to indicate the range in properties of the different products that are available. These properties will be different with different products and can only be considered as approximate and subject to increases in range as additional products become available. Not all materials are included because test programs lag behind availability of products.

Product	Type of Hardboard		
	Untreated fibrous board	Treated fibrous board	Particle board
1. Specific gravity	0.88–1.04	0.96–1.12	0.88–1.04
2. Tensile strength parallel to surface (p.s.i.)	1,000– 3,000	4,000– 5,500	1,500– 2,000
3. Tensile strength perpendicular to surface (p.s.i.)	----------	100– 200	300
4. Compressive strength parallel to surface (p.s.i.)	2,000– 4,000	4,200– 5,300	3,500– 4,000
5. Flexural strength (p.s.i.)	3,000– 6,000	7,500– 10,500	3,000– 3,500
6. Modulus of elasticity (p.s.i.)	400,000–800,000	800,000–1,000,000	400,000–500,000
7. Water absorption 24 hours (percent by weight)	9–18	5–13	15–40

Influence of Hardboard on Wood Utilization

The number and volume of present hardboard production facilities is a small part of the total volume of wood used in pulping, sawing, and plywood production, but the diversification of the raw-material sources of hardboard production indicates an important trend. It shows that hardboard and similar base products can and will utilize increasingly important amounts of the byproducts of the forest products industry that at the present time find no better use than as hogged fuel or that are burned in the thousands of sawdust burners that dot the landscape wherever sawmills or plywood mills are located.

The term "waste utilization" has been carefully avoided, because what is waste in one operation may be carefully utilized in another. The meat-packing industry is often cited as an example of ideal industrial utilization. It is said that they utilize everything but the squeal of the pig. In the forest-products industry there will probably always be some fraction that will have to be burned to provide heat and power, but this at least has the value of the cost of competitive fuel per unit of heat. It is the wood substance that ends up in the sawdust burner that is the immediate challenge. Some of the larger, integrated groups have increased their utilization to the point where they have to implement their fuel supply with outside purchases of hogged fuel or oil. Pulp mills, dry kilns, fiber mills, plywood, and special product mills are all integrated with the sawmill. The increasing use of hydraulic barkers for the sawmills makes available a quantity of clean, barkfree wood byproduct that may be used for chips for pulping for paper or fiberboard.

The raw material for hardboards may be wood substance in nearly any conceivable form. It may be whole wood of saw-log size, pulpwood, a by-product of a sawmill, woods, plywood plant, or millwork plant, or may be any species. Examples of the type of raw product used by some of the hardboard mills are given in the following paragraphs. These examples illustrate the wide range and the way that the hardboard production can help the utilization of the product of the forest.

The large producer of hardboard in the South manufactures its products from wood of pulpwood size and the species used are the southern pines and sweetgum. Its economy is essentially based on cordwood-size timber, which also is pulped for paper in large quantities in that area. Pulpwood of that size comes from thinnings, tops, and material grown for the purpose. In this company's new mill on the West Coast it is utilizing second- and old-growth Douglas-fir and redwood from logs of saw-log size, but of lower quality than those that make good saw logs. In its operation, high-quality saw logs are sold for saw timber and the lower-quality logs are utilized in the hardboard mill. Hardboard products from both operations are manufactured to the same product specifications with minor variations of the same basic processes.

It is possible for a sawmill with a properly integrated hardboard mill to bring poorer-quality logs from the woods than would otherwise be economical. One of the West-coast mills illustrates this. The source of timber for this mill is in a burn area. The hardboard mill selects the clean bark-free slabs, edgings, and trimmings for raw material for its hardboard. The remainder of the byproduct of the sawmill is used for heat and for generating electric power for the saw and hardboard mills. Thus for the hardboard mill with a capacity of about 80 tons per day, approximately 250 tons of fuel are required. This mill has eliminated the sawdust burner and is actually buying hogged fuel to augment its supply.

One other mill in that area is being observed with considerable interest. It also is making a hardboard from Douglas-fir sawmill by-products, but it is making no attempt to exclude bark from the slabs and edgings used for making hardboard. The presence of the bark imparts water resistance to the final product. If this operation continues to prove feasible, an entirely new source of raw material for hardboards will be opened. Then it may become possible with the portable chippers now available to chip trees, tops, limbs, and cull logs in the woods and haul them to the board mill. Now much of this material is being left in the woods.

One hardboard plant intends to use green planer-mill shavings for its raw product. Others use veneer clippings, waste veneer, and veneer bolts that are a residue from manufacturing plywood. A mid-western mill uses unbarked aspen that grows in great quantity in the Lake States.

A large hardboard mill is being erected to utilize defective white fir. This over-mature wood, with considerable amounts of shake and brown rot, is occupying land that should be growing a more important commercial species, such as ponderosa pine. The company building this plant will clear-cut this defective material and make hardboard of it so that the land can grow new timber. The presence of the rot apparently does not lower the strength of the hardboard appreciably, but it does increase the water resistance. That such an operation is economically and technically feasible illustrates the extent to which hardboard may be used to increase the utilization of the products of the forest.

(Continued on page 68)

Manufacture of Hardboard out of Wood Waste[1]

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BEFORE PROCEEDING to the discussion of the various processes in use today for manufacturing hardboard, it is best first to review the characteristics or properties that hardboard has that are unique to the product and that distinguish it from other wood fiber boards.

Hardboard differs from the thin wallboards of the "Beaver Board" type in general use a generation ago in that it is much harder, more dimensionably stable, more scuff resistant, and stiffer and stronger than the latter. Whereas the component fibers of the latter are merely mechanically felted like those of thick paper, in a hardboard they are bonded together to form a more homogeneous mass which, when cut with a knife, leaves a sharp, smooth edge. The bonding may result from chemical changes that take place in the composition of the fibers, or it may be brought about by the addition of extraneous binders. The binding is always done under heat and considerable pressure. While heat and pressure in themselves will produce a board of greater density, unless the pressing is done under certain unique conditions it does not produce a hardboard but merely a compressed board which swells up immediately when it gets wet to substantially its original thickness. A true hardboard, on the other hand, retains its thickness with very little swelling when it gets wet.

When testing hardboard it is therefore customary to determine the degree to which it expands in thickness when placed in water for 24 hours because the smaller the expansion, the better the product. Tests that determine its strength in cross-bending and its hardness are also made. A good hardboard will have a bending strength or modulus of rupture of 5000 psi., that is, about half the strength of wood in the direction of the grain. When placed in water, it will expand in width less than 1/10th as much as lumber. Its density is about 1.0, that is, about the same as water. Hardboards that have a density less than 1.0 generally also have a modulus of rupture of less than 5,000 psi., but seldom less than 3,500 psi. On the other hand, an increase in density over 1.0 results in a rapid rise in the modulus of rupture, so that hardboards that have a density of about 1.20 frequently have a modulus of rupture of 10,000 psi., and sometimes even higher. When manufacturing hardboard, it is therefore necessary to test its physical properties to see that its density and strength meet these requirements. In general, if a board develops a bending strength of at least 5,000 psi., its other physical properties are usually also satisfactory.

Raw Materials

As cordwood used in the manufacture of paper is not a waste product, its use for the manufacture of hardboard does not fall within the scope of this paper. It must be borne in mind, however, that most hardboard manufactured today uses cordwood as its basic raw material, due largely to the fact that sawmills from which the wood waste originates are usually discontinued when the neighboring forests have been logged. The erection of a hardboard plant represents a substantial investment, and unless the source of wood waste is completely dependable for many years' supply, it would be unwise to risk the investment. In amortizing a hardboard plant built upon the use of wood waste, it is therefore advisable to write off the investment as rapidly as permitted by the income tax laws. In the present analysis, the plant is amortized over a period of ten years. The smaller the investment consistent with efficient manufacturing procedure, the smaller the risk resulting from an impermanent supply of raw material.

Wood waste is sometimes confused with *woods* waste. By the latter, we mean the slash of defective logs and branches left over on the logging site. Experience has shown that many areas cleared of their saw logs can be economically relogged to obtain wood for paper manufacture. The harvesting of branches left in the logging site is far too expensive to be economically sound. Relogging is therefore limited to small or defective logs not originally removed. Such relogging is sometimes done several years after the original logging, and of course the wood supply so obtained must compete with cordwood or small second-growth timber cut in other areas. Its value at the mill site is, therefore, substantially the same as cordwood, which may be around 12 to 15 dollars per ton, dry basis. Mill waste, on the other hand, seldom has a value as high as this, unless the sawmill should be very close to a paper mill. The waste left in the woods is, therefore, seldom a commercially sound source of raw material for manufacture over a period of years.

All sawmills develop waste in two forms, namely in the form of sawdust and shavings, or as solid wood in the form of slabs, edgings, and end trim. Sawdust, as well as shavings, when the latter are further broken up in a hammermill, consist of small particles that are more granular in shape than they are fibrous, hence the expression used in this discussion, "granular wood hardboard." By this is meant a hardboard made of particles resembling sawdust. On the other hand, when the particles are fine and slender and consist of the natural botanic fibers or long bundles of such fibers, the manufactured board is referred to as a "wood fiber hardboard." The fibers produced in the Asplund defibrator are of this type, whereas wood chips or hogged wood put through a hammermill comes out as granules. It will also be borne in mind that by further refining or beating, wood fiber bundles may be further broken up and that wood fibers reduced in a beater may be partially brushed out into still finer constituents known as fibrils. A certain amount of fibrilization is generally desirable for the best results in hardboard manufacture. By proper choice of reduction machinery solid wood can be reduced to slender fibers, but when wood has been previously broken up into small particles of sawdust or shavings its fibrous structure has been mutilated and it cannot again be integrated into fibers. Until modern synthetic resins became available to make it possible to coalesce wood granules, all hardboard had, of necessity, to be made of fibers obtained from solid wood.

If no paper mill is nearby to which the solid wood waste could be sold, there remained only one other major use for it heretofore, namely to burn it for the production of steam. Wood develops about half the heat units supplied by the same weight of coal. If, therefore, coal is available at $8.00 per ton, then the value of waste wood fuel is about $4.00 per ton. It is for that reason that sawdust and shavings as a raw material for hardboard manufacture are assumed to be worth $4.00 per ton. Solid wood, on the other hand, can by shipping it some distance, often reach a paper mill that

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will pay $12.00 per ton or more for it. On that basis, its value at point of origin is greater than $4.00. In this paper we therefore assume the mill value of solid wood waste which can be converted into fibers to be about $7.00 per ton.

Since the advent of Masonite Pressdwood on the market about 20 years ago, other processes for producing hardboard have been developed and some of them have been put into commercial operation. Some boards involving the use of granules and synthetic resin binders are now being produced commercially, and since the manufacture of such boards promises to increase for specialized or limited uses, an analysis of their manufacturing cost is also included here.

Major Processes

The major processes in use today for the manufacture of hardboard are the following. All boards are of the fibrous type except the last.

1. *Continuous wet process.* Masonite Pressdwood falls into this category, as do most of the hardboards produced in Europe. In the case of the well-known Masonite process, partial hydrolysis of the wood is effected by high steam pressure which is followed by explosion of the fibers. The fibers are then refined, washed, and felted on a moving screen. After squeezing out all excess water with pressure rolls, the brown, damp blanks are pressed at elevated temperatures until all the moisture has been evaporated. Some irreversible binding of the fibers takes place in the press. After humidifaction and trimming, the boards are ready for shipment. The resultant brownish board is smooth on one side. No binders are used, but some waterproofing of the fibers is practiced.

The use of a small percentage of phenolic resin precipitated on the fibers has been common practice in European hardboard factories for some years. This process is now also being used in the U. S. and Canada. Similar results are, however, also being obtained by proper refining of the fibers to attain a certain freeness so that the moisture is removed in the press at an appropriate rate, and bonding is obtained through fiber interlocking resulting from some fibrilization. In the latter process, it is only necessary to waterproof the fibers by the conventional rosin size technique used in the paper industry to obtain a satisfactory hardboard. In this process, the refined size fibers are felted on a moving screen, and after squeezing out the excess moisture with rolls, the mat is hot-pressed, as usual, with a smooth plate on one side and a wire screen on the other to permit escape of water and steam. Curing in an oven at high temperatures is practiced to improve the homogeneity and strength of the board. After humidification to restore some of the moisture, the boards are ready for shipment.

The Masonite and the conventional European processes are grouped together because the fibers are carried in a water bath and deposited on a continuous moving screen. Hence the expression "continuous wet process." The process is also in use in four other hardboard factories in the U. S., one in Canada, and one near Tampico, Mexico.

An analysis of the manufacturing cost of 1/8-inch hardboard produced by the European continuous wet process will be found in Table 1, in which American conditions have been assumed. In this analysis, fiber reduction from the chips is obtained by means of Asplund defibrators. It is significant to note that the cost of the wood used is only a small fraction of the total cost, $2.45 out of a total cost of $21.70. It must also be remembered,

TABLE 1.—*Estimated manufacturing cost of 1/8-inch wood-fiber hardboard.*

Product —1/8-inch, wood fiber hardboard
Weight —700 lb. per M sq. ft.
Output —160,000 sq. ft. (56 tons) per 24-hr. day
Pressing cycle—12 min.
Investment —$1,900,000
Process —Wet, continuous felting
Amortization —10 years with interest at 6 percent
Raw material—Slabs, edgings, end trim at $7.00 per ton, dry basis
Labor rate —$1.60 per hour
Electricity —0.6c per kwh
Steam —80c per ton
Total manufacturing cost—$21.70 per M sq. ft.

	Cost, dollars per M sq. ft.	
1. Raw materials		
Wood at $7.00 per ton	$2.45	
Chemicals, resin, alum, etc.	1.30	
Total: Raw Materials		$ 3.75
2. Conversion cost		
Labor	3.85	
Steam	1.70	
Electricity	1.25	
Supplies, wire cloth, oil, repair parts, etc.	2.50	
Total: Conversion		9.30
3. Fixed charges		
Amortization of investment at $136 per year per $1,000	5.25	
Taxes at 2 percent on investment of $1,900,000	.80	
Insurance, fire, workmen's comp., est. $25,000 per year	.70	
Administration, estimated at $300 per day	1.90	
Total: Fixed charges		8.65

however, that if cordwood is used as the basic raw material, the wood cost may be doubled, bringing it to $4.90, and the total manufacturing cost to $24.15 per M sq. ft.

A plant turning out 160,000 square feet of 1/8-inch board per day is estimated to cost $1,900,000.

2. *Batch wet process.* Three factories are now producing hardboard by this process, one in the Pacific Northwest, one in the Middle West and one in British Columbia. Wood chips obtained from sawmill waste or waste veneer are reduced by conventional refining machines and a small percentage of phenolic resin is added as the binder. The stock, consisting of water and the fibers, is metered out to a deckle box where the water is drained off through a screen. The resultant mat of press size is squeezed to remove the excess water and then pressed in a hot press under a schedule of varying pressures, with a wire screen on one surface, until it is dry. The machinery involved is complex, but ingeniously designed.

A cost analysis of the manufacturing cost of 1/4-inch hardboard produced by the "batch wet process" will be found in Table 2. The estimate is based upon an output of 50,000 sq. ft. per day, or 32 tons of board. The investment is estimated at about $800,000. Here, too, it is significant to note that the cost of the wood waste used amounts to only a small fraction

TABLE 2.—*Estimated manufacturing cost of 1/4-inch wood fiber hardboard.*

Product —1/4-inch, wood fiber hardboard
Weight —1300 lb. per M sq. ft.
Output —50,000 sq. ft. (32 tons) per 24-hr. day
Pressing cycle—15 minutes
Investment —$800,000
Process —Wet, batch
Amortization —10 years with interest at 6 percent
Raw material—Slabs, edgings, and trim at $7.00 per ton, dry weight
Labor rate —$1.60 per hr.
Electricity —0.6c per kwh
Steam —80c per ton
Total manufacturing cost—$36.80 per M sq. ft.

	Cost per M sq. ft.	
1. Raw materials		
Wood at $7.00 per ton	$4.55	
Phenolic resin, 3 percent at 20c per lb.	7.80	
Total: Raw materials		$12.35
2. Conversion cost		
Labor	6.40	
Steam	1.50	
Electricity	2.35	
Supplies, cauls, screens, oil, repair parts	2.00	
Total: Conversion		12.25
3. Fixed charges		
Amortization on investment at $136 per year per $1,000	7.00	
Taxes, 2 percent on investment of $800,000	1.00	
Insurance, fire, workmen's comp., est. $18,000 per year	1.20	
Administration, estimated at $150 per day	3.00	
Total: Fixed charges		12.20

of the total manufacturing cost, $4.55 out of a total of $36.80, and that the fixed charges come to several times the cost of the wood.

3. *Semi-dry batch processes.* Three plants of substantial size are now under construction in the Pacific Northwest in which no water is to be used to carry the fibers. Instead, the fibers, appropriately coated with a small percentage of phenolic resin, are deposited on screens. They contain only enough moisture to permit grinding.

The process eliminates the expensive pumps and moving screen of the continuous wet process. No cost data are available to date on this manufacturing process.

4. *Continuous wet felting with dry pressing.* This process, in two modified forms, is in use in two substantial operations in the United States, but at this time, both operations depend upon cordwood for their raw material. If, upon expiration of certain patents the process becomes publicly available, there is no reason why some manufacturers may not resort to the use of waste solid wood as the basic raw material. The process has the commercial advantage that low density insulation board can also be made in place of hardboard. The process depends upon the fact that the fibers of low density ligno-cellulose fibrous boards (insulation boards) having a very low moisture content, when pressed between smooth platens at certain critical temperatures and pressures, will coalesce, producing a high grade hardboard having two smooth surfaces. The process is also in use in factories in New Zealand and Finland.

5. *Dry process for producing granular hardboard.* The interest in resin bonded boards is very broad, largely because the possibility of rebinding wood particles by means of synthetic resins has public appeal. To the lay public, the small amount of resin required makes the resultant board appear to have substantial commercial possibilities. To many laboratory technicians, however, the resin-bonded granular hardboard appears unsound on account of the relatively high cost of the binder.

While it is difficult to arrive at a very accurate cost of all the components that go into the manufacture of a synthetic resin granular hardboard because some of the details of manufacture are still subject to change, it is, nevertheless, possible to make a sound estimate. A breakdown of costs of a ¼-inch board made with 8 percent of dry phenolic resin will be found in Table 3. In this process of manufacture, the wood particles ground so that they will go through a 20-mesh screen are mixed in a rotary mixer with the powdered resin and then mechanically spread on steel cauls with appropriate stops to serve as side constraints. The material remains in the hot press under a pressure of about 200 psi. for 5 minutes. The resultant panel is mechanically separated from the pan, and the hot pans and the boards are conveyed away mechanically.

TABLE 3.—*Estimated manufacturing cost of ¼-inch wood granule hardboard.*

Product	—¼-inch, granular wood hardboard
Weight	—1300 lb. per M sq. ft.
Output	—50,000 sq. ft. (32 tons) per 24-hr. day
Pressing cycle	—5 minutes
Investment	—$350,000
Process	—Dry, batch
Amortization	—10 years with interest at 6 percent
Raw material	—Sawdust, shavings at $4.00 per ton, dry basis
Labor rate	—$1.60 per hr.
Electricity	—0.6c per kwh
Steam	—80c per ton

Total manufacturing cost—$44.00 per M sq. ft.

		Cost per M sq. ft.
1. Raw materials		
Wood at $4.00 per ton	$2.60	
Phenolic resin, 8 percent at 20c per lb.	20.80	
Total: Materials cost		$23.40
2. Conversion cost		
Labor	9.60	
Steam and electricity	1.30	
Supplies, cauls, oil, repair parts	2.00	
Total: Conversion cost		12.90
3. Fixed charges		
Amortization of investment at $136 per year per $1,000	3.20	
Taxes, 2 percent on investment of $350,000	.50	
Insurance, fire, workmen's comp. at $7,500 per year	1.00	
Administration, estimated at $150 per day	3.00	
Total: Fixed charges		7.70

Various vexing problems must be solved in the manufacture of a resin-bonded wood particle board, such as uniformity of density, uniformity of surface, elimination of warping and reduction of edge waste. These problems can be solved, as is evidenced by two plants on the Mississippi River that are operating successfully on a commercial scale, producing boards for use by the manufacturers in manufacturing their own products such as doors and kitchen cabinets.

With 8 percent resin content, wood particle boards can be made that compare favorably in their physical properties with the "wet batch process" boards. The capital investment of a plant having a daily production of ¼-inch board of 50,000 sq. ft., is estimated to be $350,000, which is less than half the investment of the "wet batch process" factory. It will be noted, however, from Table 3, that the manufacturing cost of the resin bonded board exceeds that of the latter process. The manufacturing cost of the ¼-inch resin-bonded granular hardboard comes to about $44.00 as against $36.80 for the latter.

All of the data above are approximate, and the results can be modified by changes in the basic rates listed. The data available indicate that about 7 man-hours of labor are required per ton of board made by the continuous process, and the batch process, and about 10 man-hours per ton for the dry-process granular hardboard.

It would appear that a thick board having a density of about .65 should be made of resin-bonded wood granules, as this thickness cannot be economically made by laminating ordinary thin hardboards. A process has been developed for producing such thick panels in ordinary plywood presses. The resultant panel is highly water-resistant, a property that is not easily achieved in a resin-bonded, low density, low cost granular board. This high water resistance is obtained, even though the pressing cycle for the ¾-inch thickness is only 10 minutes. The thick panels are remarkably flat, and veneer can be applied on one surface without warping the panel. Very little equipment is required beyond the standard equipment in use in most plywood and furniture factories. The ¾-inch resin-granule board described can be produced at less than one-half the cost of lumber cores for furniture panels.

Recognition of valuable assistance in the preparation of the cost data of this paper is due the technical staffs of the American Defibrator Company, New York City, and the American Manufacturing Company, Tacoma, Washington.

General and Technical Aspects of Prefabrication[1]

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THE TERM, prefabrication, is usually loosely used as a descriptive term for any novel construction or any method of building that differs in some marked degree from conventional construction. It is a difficult term to define. From all the definitions available and in general usage all "prefabricated" construction is "unconventional". However, it should be added that not all unconventional construction is prefabricated. One need only pick up any architectural magazine to find unconventional construction.

The earliest traces of prefabrication in America began about 1624. About a hundred years later—in 1727 to be exact—houses "all cut to be erected" were shipped from New Orleans to the West Indies for shelter of persons immediately on their arrival at a new settlement.

In 1848, the prefabrication of houses had a real impetus. In that year the California Gold Rush brought thousands of people to the Pacific coast and created an unprecedented housing shortage. To meet this demand prefabricated houses were exported to California from France, Germany, England and Belgium, and even from China, New Zealand and Tasmania. The east coast of the United States also shipped homes to California. Models costing $400 in the east brought $5,000 on the west coast.

Obstacles to Progress of Prefabrication

The prefabrication of such items as cars was readily accepted by the general public because they never knew of any other method by which cars were produced. In fact, all new products that have been successfully mass produced and distributed have either offered a quality that was substantially and radically different from that of existing objects intended for the same purpose or which offered a service that no previous object had so far provided:—the telephone, radio, automobile, refrigerators etc. are but a few examples.

In the case of the early automobile, its builders had no competition. No horse could equal the service offered by a car. Cars were a new method of transportation, the sales market was tremendous and the manufacturers of same—such as Henry Ford who began mass production in this field, were able to expand at a hitherto unheard of rate. How different was the beginning of the industrialization of housing. The Government has greatly assisted the transportation industry, canals and railroads in the form of land grants—the automobile industry, —of roads and highways—and aircraft transportation and shipping,—with vast grants of money.

The general housing industry, and certainly not the home prefabricating industry, has had no such governmental assistance, (but for one or two short lived exceptions), though housing depends as much on cheap land as does transportation.

There were and to a limited extent still are, obstacles to the very existence of the home prefabrication industry. Some of these obstacles stem in part from local building codes written in terms of specification rather than performance, and often excluding prefabricated construction. There were and are building codes containing a clause permitting new types of construction if the building inspector is satisfied. To satisfy the inspector, expensive tests had to be made at the prefabricator's expense. At times one inspector might refuse to accept the results of tests conducted and approved in another locality.

At times the prefabricator had to finance a lengthy court case involving a building code issue. Further there were obstacles created by organized labor and their passive resistance and refusal to handle prefabricated materials.

The banks and local F.H.A. offices also created obstacles by their refusal or reluctance to lend or insure loans on prefabricated homes and by making low appraisals for mortgage purposes where they did grant loans.

These obstacles have now been to a large extent removed. However, eternal vigilance is at all times required of the prefabricator of homes. For example, a short time ago a large community bordering on one of our Great Lakes, was about to amend and revise its building code. Our local sales agent was at the meeting and objected to the phrasing used in one of the proposed sections. This particular paragraph while appearing innocent enough could actually have caused us trouble because of its ambiguous nature. Inspectors could have interpreted it as excluding dry wall construction. The paragraph was rewritten to include dry wall construction.

In a recent editorial in House and Home (formerly Architectural Forum) most local building codes were classified as rackets that needlessly added a $1,000 to the cost of a small house Many local codes with their countless unpredictable, often senseless and useless variances from National Building Standards do hinder and add cost to a home.

Electrical codes requiring ceiling outlets in a living room when ceiling lights are out of fashion is an example of unnecessary waste to be found in codes. Requiring 2-inch by 4-inch studs for non-load bearing interior walls in one-story homes is another example. Two- by 3-inch studs would serve the purpose just as well, especially if no duct work had to be recessed therein.

These variations in codes discourage, retard, and often forbid the development of mass production of standard parts used in all manner of construction and also in the prefabrication of homes. If there existed similar wasteful codes regarding cars, radios, and other items common to every-day life, we would still be in the horse and buggy period—no manufacturer of cars could have gone into mass production and consequently sold in volume at lower prices if he had to produce one model for Milwaukee, another for Yonkers and still other models for other cities or limited areas.

The actual reason behind many codes or portions thereof is to keep out products produced by other than local labor. A nationwide single code covering every phase of house and building construction is essential. Such a code would help reduce the cost of homes and at the same time maintain necessary standards based on scientific facts and data.

Finally, and perhaps the greatest obstacle to the progress of our industry, is the doubt, ignorance and prejudice of the general home buying public toward prefabrication. The very word "prefab" has been coined as an abstract noun, naming the very lowest form or quality of residential shelter for man. The word has not been coined without reason, or cause, for if one remembers the many types of temporary shelters prefabricated for military installations, defense housing,

[1] Presented at meeting of the Forest Products Research Society, Midwest Section, Clinton, Iowa, October 9, 1952.

G.I. housing on college campuses, etc. during and immediately following the war years the implication of the word is self-explanatory. Consequently the great problem which the industry faces today, is to find ways and means of living down this word, and overcoming this mass prejudice.

Progress of the Industry

We, as an industry, have made great progress in this battle during the past decade. We have called on the Nation's best architects to assist with our home planning. We have established our research department to search for new and better material, less costly to obtain and fabricate. We have called upon our engineers to analyze and design the structural components of a house, to resist the loads to be imposed and to devise means of connecting these components together, in order that joints will properly transmit these loads from one component to the next, ultimately to the foundation, footing, and the earth. We have called upon production genius to devise the production processes by which the materials are fabricated according to plan and specification, through streamlined mass production organization.

We have called upon competent purchasing personnel to secure the very best materials at the very lowest price, in order to provide Mr. Home Buyer with the very best in quality at the lowest possible price.

We have called upon prominent advertising organizations to carry our message to the public, and in layman's language, to explain our construction, its quality, its durability, its beauty and cost, its meticulous attention to the many details, unseen by the home owner, that are necessary to produce quality homes. Continuously and without let-up we carry on the program of mass education of our industry's product, and to set forth our goal of producing better homes for more people at lower cost. However, though we have made great gains towards greater public acceptance, we are still faced with lack of knowledge on the part of many building officials, and professional people, who are often consulted by Mr. About to Become a Home Owner. These consultants, though well versed in conventional construction, have not become sufficiently acquainted with the engineering principles on which our construction is based, or at least in the application of basic engineering analysis to residential construction. Therefore, it is one of the purposes of this paper to bring to the attention of more professional people the possibilities of adapting such methods of fabrication as stress-skin construction to many types of construction work in addition to its use in our industry.

Finally, we have called upon the Nation's great research institutions, and we are most certainly in great debt to them for providing the basic and fundamental concepts from which our fabrication takes root.

The method of erecting and building directly affects the quantities of time, labor and materials required and thus the ultimate cost. Different methods are used in different types of buildings and under different conditions of climate and terrain. In the construction of homes these methods may be divided into three types:—

(a.) The most costly method, whereby each piece is separately cut and erected in its proper place.

(b.) The precut method, whereby all parts of a complete section are precut in one place and then assembled and set into the structure in the proper place at site.

(c.) The third and most efficient method is what is commonly called prefabrication—whereby a complete section is built up as a unit and set up in the structure. To realize to the fullest the economies of the latter method production in quantity can realize even greater economies through centralized supervision, standardization of parts, elimination of waste, more efficient use of manpower and methods of construction. Further, production can be carried on in every type of weather and the working conditions of employees can be considerably improved. Lastly, prefabricators have their own research and engineering departments, which at all times strive to improve the products and secure additional savings.

Fancy vs. Fact

In a number of consumer polls conducted by various organizations—such as Curtis Publishing Company in 1944—approximately 80 percent of those polled indicated preference for so called conventionally built homes. The reasons given by most of the 80 percent for lack of interest in prefabricated homes was—(1.) Lack of strength (2.) Not warm enough (3.) Not permanent.

A good many of these opinions spring from the fact that lightness of structure is being confused with weakness, and speedy erection with nonpermanence.

Generally, Mr. Home Buyer is concerned with the apparent lack of strength of the prefabricator's walls, and perhaps in our case our unconventional floor construction. He is not so much concerned with our roof construction, since the main load carrying members are conventional fink-type roof trusses.

In the assumption of lack of strength in our wall construction, the average home buyer considers wall thickness as the only indication of strength. He does not know that it is possible to fabricate walls using smaller members than those used in conventional construction, and at the same time build a wall considerably stronger and more rigid than average conventional frame construction.

The Forest Products Laboratory has tested and compared the several types of frame wall construction, including walls similar to our stressed skin construction, and their results indicate that the stressed-skin type wall is stronger and more rigid than the average conventional walls, under racking loads. They have found that plywood ¼ inch or more in thickness bonded to studding and plates offers a wall almost twice as rigid and approximately 35 percent stronger than a like wall having plaster on wood lath, and horizontal sheathing. Under transverse load tests, prefabricated walls using 2-by-3 studs with stressed covering instead of 2-by-4 conventional constructed walls, have met the deflection requirement for dry wall construction of the major building codes, and our own industry's commercial standard.

In our own laboratory, transverse tests on our walls indicate that we even meet the deflection requirement for plastered walls, at our design load of 30 pounds per square foot.

In considering compressive load on our walls the basic roof design load transmitted and sustained by the exterior stress-skin walls, is 40 pounds per square foot of horizontal roof projection. This load is transmitted to our walls by means of trusses, spaced 4 feet on centers, with each truss bearing on the top plate with approximately 1,800-pound reaction. This is approximately equivalent to 450 pounds per lineal foot of wall length. Tests on similar construction conducted by an independent laboratory, indicated that this type of wall sustained a load of over 3,000 pounds per lineal foot of length before first signs of failure occurred. This is over six times the design load.

Our P&H floor construction consists of ⅝-inch plywood subfloor, bonded to box beam floor joists spaced 2 feet on centers. The box beams are approximately 4 inches wide and 7½ inches high, consisting of $\frac{5}{16}$-inch plywood web and 1-by-4 Douglas-fir flanges, with 2-by-4 blocks for web stiffeners. All parts of the box beams are assembled by gluing and nailing.

Engineering analysis shows that under a total design load of 50 pounds

per square foot, our floor deflects about 0.228 inch or approximately ¼ inch on a 12-foot span. Permitted deflection for floors where the under surface is not to be plastered is 1/270 of the span length which in this case, is equal to 0.53 inches or about ½ inch. A conventional floor consisting of nominal size 2-by-8's placed 16 inches on centers deflects under the same loading 0.339 inches or about 11/32 inch. Therefore, our floor is more rigid than a comparable conventional floor. This fact has been substantiated in our laboratory tests.

Our roof construction, conventional fink-type trusses, placed on 4-foot centers, and designed for a 30-pound-per-square-foot live load, have been tested in our laboratory and found to sustain over three times this load.

In connection with the belief that our construction is not well insulated, let us consider the walls of several different homes.—The exterior face of our exterior wall consists usually of a double course of wood shingles or clap board with building paper nailed on $\frac{5}{16}$-inch Douglas-fir plywood which is glued and nailed to 2-inch by 3-inch studs. Between the studs 1-inch thick glass wool batts are glued to the $\frac{5}{16}$-inch plywood. The inside face of the exterior wall is of ⅜-inch Upson Strongbilt board, having a vapor barrier surface. The Upson board is likewise glued and nailed to the studs. Between the glass wool and Upson board is a dead air space. This construction gives us an exterior wall having a heat transmission coefficient (U) of approximately 0.131 and an estimated inside surface temperature of 62.8° F.

A conventionally built wall with lap siding ¾-inch fir sheathing and building paper, an air space in the wall, 1-inch flexible insulation and ½-inch plaster on ⅜-inch gypath on inside surface, would likewise have a heat transmission coefficient of approx. 0.13. If, however, as many conventional houses are built, there is no flexible insulation, but instead 25/32-inch rigid insulation board is substituted for the ¾-inch fir sheathing, we get a heat transmission coefficient of approximately 0.19 revealing a good deal less efficiently insulated wall than our construction. Therefore, our wall has approximately 45 percent less heat loss than the conventional construction mentioned above.

Concerning the erroneous belief, that prefabricated construction is not permanent, the quality and treatment and fabrication of the material which we use in our construction is as good, or better than those found in conventional homes, because of rigid specification standards set forth by our company. However, no matter how good a house is at the time of construction, the ultimate life depends as much on the care and maintenance given the house, as on the construction standards.

One of the most important phases of producing a quality home of any type is the care used in the selection and purchase of proper material. We purchase our materials under specifications set up by our engineering department, and maintain an inspection department to thoroughly inspect all incoming materials for specification compliance.

The material used in our P&H construction are as follows:

No. 2 & Btr Kiln Dried Douglas-fir and larch is specified for all structural parts, except that No. 1 & Btr Douglas-fir and larch is used within our box beam construction, where grade is of utmost importance. C-Select white fir and D-Select ponderosa pine, kiln-dried, is used in manufacturing trim parts and mouldings, much of which is further cut to clear where use as interior trim dictates.

Douglas-fir plywood is used as a component for many structural parts, exterior grade being used where risk of exposure demands, and where F.H.A. Minimum Property Requirements justly dictate. The webs of our plywood box beams employ exterior-grade plywood, as do also the gusset plates used in making our truss joints. Of course, where plywood is used on the exterior of the home, exterior grade is always specified. However, most of the plywood used in P&H construction for exterior walls and roof sheathing is interior grade as permitted by F.H.A. and recommended by the Douglas Fir Plywood Association.

Two types of adhesives are used in fabrication. Waterproof glue of resorcinal resin type being used in all structural assemblies, where severe exposure conditions demand that maximum protection be afforded.

Water resistant glue of the casein type is used in structural assemblies, where severe exposure conditions do not exist, but where the highest quality bond is required to develop structural strength. For example, waterproof glue is used in the assembly of our box beam joists and floor panels, in the bonding of our exterior wall sheathing to studs and plates, and in the fabrication of trusses. Water resistant glue is used in the attachment of the room side wall covering to exterior walls and partition.

Upson Strongbilt panel is used as dry wall covering, two types being used. Upson panel with vapor barrier coating is used on all exterior walls, while Upson panels of the waterproofed type is used on all interior partition walls. We use Upson panel, because it is the only low cost material available today, manufactured in large sheets, affording us the opportunity to build walls and partitions of room size lengths, free from cracks and joints. Further, with the recent development of the process for applying vapor barrier coating to the back side of the Upson panel, we have attained an excellent vapor barrier, at low cost. A vapor barrier, whose performance is no longer dependent on the care of installation within the wall, thus assures the home owner excellent protection, so necessary in today's tight construction.

Finally, the miscellaneous materials such as doors, windows, hardware, and so forth, must be of the best quality, for our own protection as well as for the home owner's benefit, as we must stand behind our product in the years to come.

Trends in the Industry

Prefabricators are usually the first to test any new product or method of construction. If the innovation proves satisfactory we and those who follow us in its use are rewarded in some measure. If, however, the new product or method proves unsatisfactory we let it die in the research department. All builders usually fall in line with the public demand, when any new product or method of construction is found to have a great appeal to the buying public.

As the industrialization of the building industry continues there will be continued expansion by the more efficient prefabricators. But there is little likelihood that there will ever be a Detroit of the prefabricated home industry. The ever rising shipping costs, plus the fact that a house is a heavy and bulky object, makes decentralized production an economic necessity.

Mass production and mass distribution through brand name selling is one of the important advantages offered by prefabrication. Most prefabricators engage in advertising in addition to their brochures, usually in local newspapers and in trade journals. Quality, however, is more important than a brand name. There have been poor houses produced by fabricators with brand names, so that their widely publicized ventures come to naught.

Quality indeed is more essential to continued business success for a prefabricator than for the average conventional builder. An average conventional builder usually has a short-term interest in the house he builds and it is usually sold without guarantees, advertising, servicing, or a brand name

(Continued on page 70)

Paper-Honeycomb Cores For Structural Sandwich Panels[1,2]

ROBERT J. SEIDL

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BONDING OF PAPER-HONEYCOMB CORES between thin and strong facing sheets results in sandwich panels that are becoming increasingly important for structural applications. The panels are strong, stiff, light, and economical of raw materials. They can be made by processes that lend themselves to mass production from materials that are produced in large volume.

This paper summarizes briefly some of the research at the U. S. Forest Products Laboratory on sandwich building panels having cores made from corrugated paper of low resin content. Extensive testing of these panels in the wet and dry condition has shown that satisfactory performance could be expected, and a considerable amount of data has been obtained to aid in the structural design of panels. For use in dwelling units, strength tests have indicated that a suitable sandwich wall panel is comparable to conventional house construction in bending strength and resistance to vertical loads. With proper treatment, the cores have reasonably good decay resistance. Thermal insulation values are relatively good and depend on the core density and specific construction; for some uses, the thickness of the panel may be determined by the thermal requirements. Insulation values can be further improved by filling cells with materials such as foams or loose insulation.

Bowing of panels due to differential moisture and thermal conditions was found to be of approximately the same order as that of insulated, stressed-facing panels made of plywood glued to wood frames. The fire resistance of honeycomb panels is appreciably higher than nearly hollow panels with like facings. Filling of cells with foamed resin further increases fire resistance. Results of accelerated aging tests are favorable. Durability and bowing under outdoor conditions are under study in a sandwich-panel test unit, built in 1947, which is still in very good condition.

[1] Presented at a meeting of the Plastics Committee of the Technical Association of the Pulp and Paper Industry, Syracuse, N. Y., Nov. 9, 1951.

[2] Acknowledgment is made of information used in this report based on the work of various investigators at the Forest Products Laboratory and on work done by the Laboratory in cooperation with the Housing and Home Finance Agency.

[3] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Introduction

The principle of the sandwich panel was undoubtedly put to effective use for many years before it was defined by engineers and recognized as a separate type of construction dominated by certain mathematical principles. General recognition occurred during the accelerated search for high-strength, light-weight materials for aircraft in World War II. Simply stated, a sandwich panel consists of an appreciably thick core of a low-density material bonded on each side to a thin sheet of strong, stiff material. A great variety of facing materials, such as wood, hardboard, asbestos board, aluminum, and plastic laminates, have been bonded to many lightweight core materials such as balsa wood, rubber, plastic foams, and formed sheets of cloth, metal, or paper.

The new and ingenious materials, constructions, and ideas for use multiplied rapidly. Stringent demands for strength and special characteristics were set by designers to meet needs for wartime aircraft. As the development progressed, a distinction between highly specialized aircraft panels and other general building panels became evident. Obviously, a radical change in the outlook regarding materials, properties, and economics was indicated, although the principle remained unchanged. Demands for strength appeared less exacting and requirements for durability and thermal insulation were perhaps more critical for building panels than for aircraft panels. Problems of supply and cost were paramount for building panels. Cores made of sheet materials, such as cloth, nonwoven fabric, or paper formed into cellular configurations of one kind or another, became more important. When careful consideration was given to economics, availability, and other properties, it became increasingly clear that paper would play a very important part in the large-scale development of honeycomb. It may indeed be only a slight overstatement to say that paper is almost the only material apparent at present for the large-scale development of high-strength honeycomb panels.

In 1947, following several years of research with lightweight, paper-core constructions and sandwich panels at the Forest Products Laboratory, the status of the work was reviewed from the standpoint of panel applications in building. Many of the most promising ideas were gathered together and crystallized in the form of a sandwich-panel test building unit for outdoor exposure (11).[4]

Since the erection of the test unit, a continuing interest in the structural sandwich panel has developed, as indicated by the large number of inquiries received from an unusual variety of sources. Many are interested in only certain phases of the development, such as fabrication of the core or pressing of the panels. Pulp and paper mills endeavoring to increase the number of products possible from their raw material consider the sandwich panel as an additional long-term outlet for paper. Some resin manufacturers consider that manufacture of sandwich panels provides a promising use for their products in core treatment and in plastic sandwich facings. A few boxboard mills have observed the similarity between their regular products and the honeycomb and are following the development closely, thinking perhaps of the application of boxboard experience to honeycomb and, conversely, honeycomb principles to boxboards and containers.

Plywood and veneer mills are interested in sandwich panels as a means of increasing the monetary yield from a given supply of logs. Metal companies ask about the feasibility of using metal as facing material and see in the sandwich panel an opportunity to use thin metal sheets for applications where they previously were not suitable. The advantages of sandwich construction in furniture and doors are evident to makers of these products. Architects and builders interested in new building materials inquire about strength, fire resistance, and thermal insulation afforded by the honeycomb core, feasibility of using sandwich construction in buildings, and possible sources of sandwich panels.

Makers of hardboards and composition boards visualize new and interesting uses for their products. The continuous support that they provide makes fiberboards themselves suitable for items such as walls, partitions, and doors. When fiberboards are used as

[4] Numbers in parentheses refer to literature cited at end of report.

facings, the possibility of making high-strength structural panels from pulpwood and woods residues is evident.

Basically, the problem of making honeycomb from paper can be viewed as one of "blowing-up" a certain volume of a dense paper to yield a much larger volume of a low-density cellular structure with certain properties. After the spacing between sandwich facing has been determined by design, the honeycomb must fill all of the volume between the facings. Density of core is therefore one of the key factors in economy, as the materials are relatively costly on a weight basis, and they must be made to provide the greatest possible volume consistent with adequate properties.

Paper can be "increased in volume" to produce core in numerous ways. Three of the more prominent types used for sandwich panels might be described as "expanded," "figure 8," and "corrugated." In the expanded type, sheets of treated paper are laid up and interspaced with parallel and uniformly spaced strips of adhesive. Successive strips of adhesive are placed so that the centers of any one layer are positioned at midpoint between the strips of the preceding and the succeeding layer. The blanks after bonding are expanded to form hexagonal cell sections, as shown in Figure 1. There has been an increasingly large interest in honeycomb structures of this type (1, 2, 4, 5, 7).

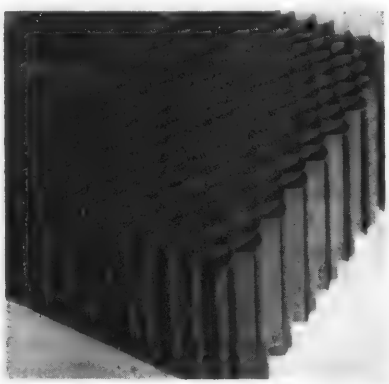

Figure 1.—Expanded type of core consisting of sheets of paper interspaced with parallel strips of adhesive and expanded to form hexagonal cell sections.

To produce the figure-8 core, a ribbon of paper is looped and bonded to form circular cells resembling a figure 8 in cross section, as shown in Fig. 2. For the production of either the figure-8 type or the expanded type, special machines are required.

To produce the corrugated type of honeycomb, the cell or flute is made by hot forming paper between fluted rolls on equipment of the type used in making corrugated container board.

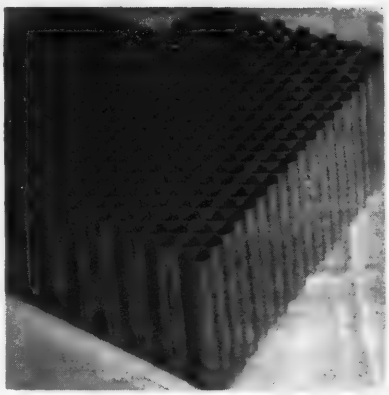

Figure 2.—Looped or figure-8 type of core consisting of sheets of paper looped and bonded to form circular cells.

The corrugated sheet, with or without uncorrugated interleaving sheets, can be assembled in many ways. The three types discussed chiefly in this report are shown in Figures 3, 4, and 5.

Each type of core has advantages and disadvantages peculiar to its construction. The differences lie in equipment needed for production, limitations in resins and adhesives, relative difficulty of accurate cutting, strength, thermal insulating properties, ease of shipment, and other factors. As far as the base material and resin treatment are concerned, such problems as fiber, resin, wet strength, and durability are substantially common to all types. It was therefore intended that the results of this work should apply to any honeycomb structure made from paper treated with phenolic resin, although most of the data were obtained from sandwich panels having corrugated paper cores.

This report summarizes some of the research that has been conducted at the Forest Products Laboratory on the structural type of corrugated-paper-honeycomb cores for use in building panels, as distinguished from use in

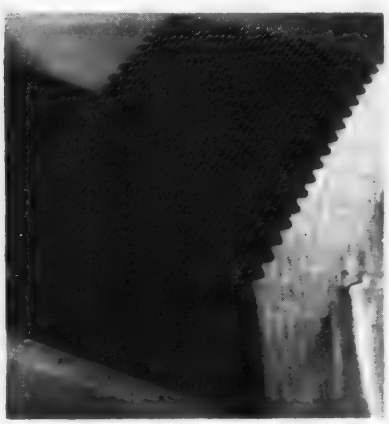

Figure 3.—Corrugated type of core designated as PNL. It consists of corrugated sheets of paper assembled parallel to each other and separated by a single treated, and uncorrugated sheet.

aircraft. Consideration is given to the resin treatment of the base material and to the fabrication of the core and sandwich panels in the interest of low-cost building material. Strength properties, bowing, thermal properties, durability, and fire resistance of the sandwich panels are discussed. Figure 6 shows a structural sandwich wall panel.

Base Paper

For most experimental work on sandwich panels at the Laboratory, an unsized, neutral kraft paper was selected, because it was strong, potentially available in large quantities, and had favorable indications of permanence. The paper contained no sizing in order to permit better resin penetration and to favor permanence.

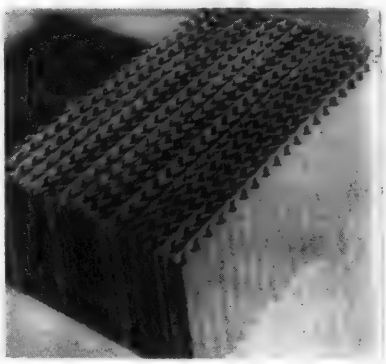

Figure 4.—Corrugated type of core designated as XN. It consists of corrugated sheets assembled with principal flute directions of adjacent sheets at right angles.

A 50-pound (weight per 3,000 square feet) paper was usually employed for cores having cells of A-flute size. Tests were made to explore the possibility of reducing the weight of paper without undue sacrifice of strength in the sandwich panel. The use of lighter-weight papers results not only in an economy of base material but also in a reduction in the

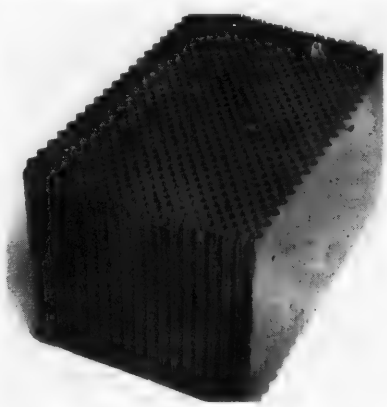

Figure 5.—Corrugated type of core designated as PN. It consists of corrugated sheets assembled parallel to each other and bonded at the crests.

amount of saturating resin required to produce a given volume of core. Results showed that sandwich panels with surprisingly high strength properties could be made with paper weighing only 30 pounds per 3,000 square feet, which yielded core of a density of about 2.5 pounds per cubic foot. Thermal insulation data obtained on these core constructions showed that, for a particular core construction, an improvement in thermal values could be achieved by reducing the weight of the paper. The lower limit of paper weight was not determined, as it was felt that paper of much lower weight than 30 pounds per 3,000 square feet would be difficult to handle in the corrugating and fabricating process.

No information is available on the minimum strength requirements of the base sheet for satisfactory core structures. The relation between ordinary properties of paper and the properties of cores is obscure, and studies should be made to overcome this deficiency. Wet strength can indicate the effectiveness of the resin treatment, ring compression of the sheet may have some significance, and accelerated aging may indicate permanence. Compression, tensile, and shear tests on assembled core are informative but are costly and occur too late to assist paper makers in producing suitable papers.

Until the requirements of paper for use in core can be defined in a more usable form, it will remain difficult to determine the best papers for particular uses. At present, it is certainly safe to assume that any of the ordinary chemical pulps are suitable. For many applications, especially those involving short time expectancy for which maximum permanence is not essential, a high-yield or semichemical pulp may be acceptable or even preferable for structural uses. Reclaimed paper may also provide a suitable fiber for certain panels. Few data are available on the permanence of the high-yield or semichemical pulps. The permanence of the paper may not, however, be critical, since the core material in the sandwich panel is protected from ultraviolet rays, which contribute to the loss of strength of paper upon aging.

Resin-Treated Paper

One of the first problems common to any paper core is that of resin treatment of the paper. Although in some cases paper without resin might be acceptable, it is assumed that for general usage only resin-treated papers can be considered. Since panels are likely to be subjected to damp or wet conditions, the presence of resin in the paper is necessary to yield a product that is permanently strong and stiff in the wet condition. Even small amounts of certain resins can be effective in this respect. In terms of tensile strength, it is not difficult to produce a paper that retains over 75 percent of its strength when dry after water soaking that would cause untreated paper to lose almost all of its strength.

The work reported relates to the use of phenol-formaldehyde resins of several types. Two of these are water-soluble and alcohol-soluble types and, although both are suitable, they have inherent differences that need to be considered when they are used with cellulose. With solutions of water-soluble resins, the swelling effect of the water on the fiber permits the resin to penetrate the fiber itself and through a "bulking effect" (10) to maintain the fiber in a swollen state. This also causes a reduction in the equilibrium moisture content of the sheet with water vapor. When alcohol-soluble resin is applied in the absence of a swelling solvent, the effect appears to be chiefly one of coating the fibers. The equilibrium moisture content of such paper, when based on the oven-dry weight of fiber alone, is nearly as high as that of untreated paper (3). Both may have high levels of strength in the wet condition.

Figure 6.—Structural sandwich wall panel tested under vertical load.

Additional evidence that the water-soluble resin penetrates the fiber better than alcohol-soluble resin was indicated by decay tests made on paper treated with both types of resin (8). The results showed that a paper treated with 15 percent of water-soluble resin has considerable resistance to decay fungi, as measured by strength, while the paper containing an equal amount of alcohol-soluble resin lost most of its strength under similar exposure conditions. While the water-soluble phenolic resins are not especially good as fungicides, they can reduce the equilibrium moisture content of the paper and thus discourage the growth of fungi. Inherent brittleness may be a disadvantage of paper impregnated with water-soluble resin.

A resin treatment of 15 percent of water-soluble resin (based on weights of resin and fiber) was found to be adequate for providing paper of good strength when wet, decay resistance, and handling characteristics during corrugation and subsequent fabrication. Resin content in excess of about 15 percent does not seem to produce a gain in strength commensurate with the increased quantity of resin required. The tensile strength of a kraft paper treated with 15 percent of water-soluble phenolic resin may be greater when wet after prolonged soaking in water than the strength of the untreated paper when dry.

Although more than 15 percent of resin may be required for certain uses, it is promising that even a lower resin content will be acceptable for most applications. In one series of tests, paper with as little as 5 percent of water-soluble resin was satisfactory in strength but showed less resistance to decay organisms than a paper with 15 percent of resin. In this case, the addition of 2 percent of pentachlorophenol in the paper overcame the deficiency in decay resistance. The pentachlorophenol was dissolved in a small

amount of ethyl alcohol and added to the resin. The concentration of the solution was further reduced by adding a mixture of 50 percent each of water and alcohol. Using this mixture, a kraft paper was treated with 5 percent of a water-soluble phenolic resin and 2 percent of fungicide. The pentachlorophenol did not seem to affect the cure of the resin as indicated by the good strength values of the treated paper and honeycomb structures when wet. Negligible losses in strength resulted from paper impregnated with 5 percent of resin plus 2 percent of pentachlorophenol after 2 months' exposure to two types of wood-destroying fungi. No data are available to indicate the minimum amount of pentachlorophenol required for good decay resistance, but it is likely to be less than 2 percent.

Since resin is the costly item in the honeycomb structures, a series of tests was made to compare the properties of cores containing 5, 10, and 15 percent of water-soluble phenolic resin and 15 percent of alcohol-soluble resin. These cores, of the XN type (Fig. 4) with a density of about 2.5 pounds per cubic foot, were bonded to plywood facings, and the panels tested for shear and compressive strength in both the dry and wet condition. When tested dry, panels with 5 percent resin content had a shear stress of 52 pounds per square inch and a compressive strength of 35 pounds per square inch. Increases in saturating resin content of the core resulted in an increase in both strength properties of the panels. Increasing the water-soluble resin content of the core from 5 to 15 percent increased the shear strength of the panels about 40 percent in the dry condition and about 300 percent in the wet condition. The effect of resin content on compressive strength was not so great as on shear strength. The use of the alcohol-soluble resin as a saturant resulted in slightly higher shear stress developed in bending and compressive strength for dry panels but lower strength for panels tested wet.

Impregnating paper with resin on a separate impregnating machine is likely to be somewhat costly, as it involves a secondary operation. Because the resin content of the paper in the honeycomb core is in the low range, it is reasonably simple to apply resin during the process of paper manufacture as a means of reducing costs if the tonnage required can justify such a process. It is possible to add resin during paper manufacture by:

1. Applying it at the paper-machine size press or similar device.
2. Blending of fiber and resin in water suspension in the beater and retaining this resin in the sheet during paper making.
3. Continuous addition of liquid resin at the machine headbox.

On the experimental paper machine at the Forest Products Laboratory, papers with a wide range of resin content were readily prepared by use of the size-press equipment. These papers were comparable in most respects to matched sheets treated on a separate impregnation machine with the same resin. From numerous experimental trials, it appeared that the size-press treatment was one logical step toward the realization of a lower-cost core material.

In recent years, suitable resins were developed for addition to both the beater and the paper-machine headbox. The retention of early beater-added phenolic resins was very poor, operating difficulties were numerous, and large chemical addition was required to properly precipitate the resin. Several resins exist today that are suitable for this type of addition, and experimental paper-machine runs have been made with promising results. In one series, the addition of 12 or 20 percent of this resin to the pulp slurry tended to free the stock on the machine wire and indicated no special operating difficulties. This is in sharp contrast to the "slowing" of stocks by resin addition in earlier years. The paper after cure of the resin was considerably less brittle than sheets treated with water-soluble phenolic resin on a resin-impregnating machine or size press. An indication of the toughness of the sheet was given by sharply creasing the sheet by hand and then obtaining a tensile strength value across the folded area. The paper retained a surprisingly high percentage of its original strength. Microscopic examination of the papers containing beater-added resin, using an Ultropak microscope equipped with fluorescent lighting, showed only a faint haze of resin, indicating very small particle size and excellent dispersion.

Core Fabrication

Paper for the corrugated type of honeycomb used in this study was corrugated on a 50-inch machine at the Forest Products Laboratory. The A-size fluted rolls common to the box industry were used. The procedure and weight of paper were varied as needed, depending on the nature of the core desired. Simplest from the standpoint of adaptability to existing equipment is the PNL type of construction (Fig. 3). This consists of alternate corrugated and flat sheets and is made by cutting the continuous web of single-faced corrugated paper and bonding these sheets into blocks of considerable thickness, almost exactly as is now done in making blocks for insulation or cushioning in packaging. The only difference, in fact, is in the use of treated instead of untreated paper. In order to make the PNL type of core with A flutes and a density of 2.5 to 3 pounds per cubic foot, it was necessary to use a paper of about 30-pound basis weight (per 3,000 square feet). This core had certain attractive features, such as excellent strength, a slight compressibility in one direction, which aids in fitting pieces of core into a panel of predetermined width, and ease of manufacture.

The XN type of core (Fig. 4) was used for most of the data given in this report. To fabricate this type, corrugated sheets were assembled with the principal flute directions of adjacent sheets at right angles and bonded at the crests to form a block of core material. No uncorrugated facing sheet was used for this construction. The base paper, a 50-pound (per 3,000 square feet) kraft paper impregnated with approximately 15 percent of water-soluble phenolic resin, yielded cores with a density of about 2.5 pounds per cubic foot. To assure a good bond between adjacent cross-bonded sheets of corrugated paper in the core, a phenolic adhesive was used in an amount equal to about 10 percent of the weight of the core.

The core was cut and assembled in the sandwich panel with one-half of the flutes perpendicular to the facings. The flutes in the other half of the corrugated sheets were parallel to the facings and contributed very little to the strength of the core, but served rather as spacers for the flutes that carry most of the load. It was demonstrated that the basis weight of the spacer sheets could be reduced from 50 pounds to 30 pounds per 3,000 square feet with very little effect on strength properties of the panel. A further economy in cost could also be realized by reducing the resin content of this lighter paper.

The production of large volumes of this type of core would require certain changes in existing commercial corrugating equipment. Pasting of a flat sheet to the corrugated web is omitted, and more care is needed in handling the web without stretching the corrugations. The crossing of the corrugated sheets would require special but relatively simple equipment.

Either the PNL or the XN type of core can be assembled in the panel so that all the flutes are parallel to the facings of the panel instead of per-

pendicular. This results in a great improvement in the thermal insulation but a loss in strength. The principal disadvantage of this flatwise construction is that the integrity of the panel itself depends on each glue line between the sheets as well as on the glue line between core and facings.

The PN construction illustrated in Figure 5 is similar to the PNL type except that the flat sheet is omitted. The PN type is probably the most difficult of the various corrugated types to fabricate, since it involves placing all corrugated sheets parallel, the crests of each sheet being in direct contact with the crests of adjacent sheets. To make experimental amounts of this core, segments of ordinary soda straws inserted at the four corners of each sheet were used to achieve good crest-to-crest alinement. This type of core has certain ideal features for studies of materials and design factors. A considerable amount of study was based on this type of core, particularly as related to specialized aircraft parts (6, 9).

Most of the early work in making cores involved the use of costly adhesives to bond paper sheets to each other. In order to better accommodate existing machines and to provide greater economy, a study of the effect of the quality of the bond between sheets of paper on the properties of the sandwich was made. In the assembly of ordinary corrugated board, a nonwater-resistant adhesive is usually employed. It was hypothesized that the bond between individual sheets within the honeycomb core was not critical, since the ends of each flute were bonded to both facings with a high-quality, water-resistant adhesive. The cost of the adhesive and the equipment necessary to use such an adhesive are uneconomical features in the process, unless the high-quality bond is required.

A series of tests was made to compare panels having cores in which individual sheets were bonded with (a) phenolic resin, (b) urea resin, (c) sodium silicate, and (d) no adhesive. Although the assembly of corrugated sheets in a panel without the use of a sheet-to-sheet adhesive is impractical, it was reasoned that the resultant properties would establish the lower limits of strength. The nature of the crest adhesive appeared to have only a slight effect on the shear strength of panels tested in either the dry or wet condition if the web of the corrugation was parallel to the span. Panels with the silicate adhesive had slightly higher strengths when dry and slightly lower strengths when wet than those with the phenolic-resin adhesive. These tests demonstrated that it was desirable to have the web of the corrugation parallel instead of perpendicular to the span to obtain maximum strength, regardless of adhesive used.

Sufficient commercial trials have been made to demonstrate the feasibility of running impregnated papers on corrugating machines, and such papers have been corrugated at ordinary commercial speeds. The ordinary size of flutes used in the box industry produces satisfactory core, but, for economy, it is desirable to use a much lighter paper than the usual corrugating medium for boxes. Another and possibly better approach would be to use larger flutes and heavier papers, resulting in a faster bulid-up of core of a given density. A few existing machines have larger flute sizes, and any new machine designed expressly for this purpose undoubtedly should use larger flutes.

Panel Manufacture

Facings

Any honeycomb core is satisfactory only in relation to the facings it supports and, conversely, the suitability of any facing may depend on the core. Perhaps one of the best long-term advantages of the sandwich panel is the great latitude it provides in choice of facings and the opportunity to use thin sheet materials because of the nearly continuous support by the core. The stiffness, stability, and, to a large extent, the strength of the sandwich are determined by the characteristics of the facings. There are a wide variety of sheet materials suitable for facings or skins on honeycomb cores. Some of the different types that have been used include plywood or single veneers overlaid with a resin-treated paper; hardboards; asbestos board; metals, such as aluminum, enameled steel, stainless steel, or magnesium sheet; wallboards; fiber-reinforced plastics or laminates, and veneer bonded to metal.

Plywood is a versatile facing material, and the performance of panels with such facings can now be well predicted. It has good dimensional stability characteristics and strength properties and can be dependably bonded to core with proven adhesives. When exposed to outdoor conditions, some plywoods, such as Douglas-fir, may check considerably, and grain raising becomes apparent. These defects may be eliminated to a large extent by applying a resin-treated paper-overlay sheet to the outer face of the panel, resulting in a smooth surface and uniform base for painting.

Since the facing is securely bonded to the core in the sandwich panel, a two-ply veneer facing, with or without an overlay, can be used as in making flush doors. Although each facing is unbalanced, the panel itself is in balance. Sandwich panels with dissimilar facings may also be suitable for certain uses if the proper unbalance is selected. These might be considered in cases where the exposure conditions on each side are not in balance. Unbalanced panels, however, should be used only with considerable caution. Panels with facings of hardboard or veneer with paper overlays are promising panels from the standpoint of being lightweight and economical. Excess dimensional movement may limit use of this type in some cases.

Cutting of Core

In assembling the core for fabrication of the sandwich panels, the cutting of strips of core material to accurate thickness is essential to avoid difficulty in making or using the panels. Core material may be reduced to the desired thickness by sawing on a circular saw, band saw, vibrating knife, or, in some types, by a guillotine cutter. It may also be made to the desired thickness to avoid cutting. An accurate cut can usually be made with a circular saw, but this requires a rather thin section and therefore more cuts. With the proper blade, speed, and technique, a band saw will reduce the core blocks to proper size within $\pm$ 0.015-inch tolerance, which is probably sufficient for panels of 2 inches or more in thickness. A band saw with five teeth per inch, operating at a blade speed of 3,500 feet per minute, was found to be suitable for most of the test panels. A vibrating-knife type of cutter may be suitable for cutting honeycomb core, because it eliminates the saw-cut losses. For commercial production, it may be desirable to cut the core initially to a broader tolerance and control the thickness accurately with a sander or other machine. It may be sufficient to simply roughen or slit the edges of the core, so that, when pressure is applied to the panel in the press, the effective thickness will be uniform.

Pressing

Satisfactory performance of the sandwich panel depends to a great extent on the bond between the core and facings. The development of sandwich panels was made possible, in fact, by the introduction of high-quality adhesives in recent years.

A study was made of the durability of a number of typical exterior resin adhesives. Paper-honeycomb core made from paper treated with 15 percent of resin was bonded to plywood and tested in tension and shear after exposure to a number of extreme tem-

perature and moisture cycles. The following adhesives produced sufficiently strong bonds between the core and facings to force a high percentage of failure in the core:

(a) An acid-catalyzed, high-temperature-setting, phenol-resin adhesive.

(b) An alkaline-catalyzed, intermediate-temperature-setting phenol-resin adhesive.

(c) An alkaline-catalyzed, room-temperature-setting resorcinol-resin adhesive.

(d) An alkaline-catalyzed, high-temperature-setting, phenol-resin adhesive.

The bonding of most of the experimental sandwich panels was done in hot-press equipment. For laboratory work, the short pressing cycle and the long assembly time favored the acid-catalyzed, high-temperature-setting, phenol-resin adhesive. Adhesive was applied to both the core and facings with a rubber roller or an ordinary paint roller at the rate of about 22 grams per square foot of surface, one-half to the core and one-half to the facings. It was also demonstrated that it may not be necessary to apply adhesive to the core in order to produce a satisfactory bond. Core and facings were allowed to stand after spread of adhesive to permit the evaporation of the solvent. Panel components were then assembled and placed in a hot press at a temperature of 230° F. (for the acid-catalyzed phenolic adhesive) to cure the adhesive. Pressures ranging from 15 to 50 pounds per square inch were used, depending on density and type of core construction. Test panels up to 14 feet in length and 6 inches in thickness were made in a 4 by 4-foot laboratory press using step-pressing techniques. Flat sandwich panels were produced with this method.

Special presses are indicated for sandwich-panel manufacture. The pressures required are usually lower than can be obtained in the range of good pressure control on ordinary plywood or plastic presses. Because pressure requirements are low, simple and perhaps less costly presses could be used. Continuous roller presses or bag-molding equipment may also be suitable. Certain special problems arise in the pressing of sandwich panels, but their manufacture is basically not complicated.

Pressing of sandwich panels having dissimilar facings in hot presses has been difficult because of unequal dimensional movement of the facings due to moisture or thermal changes. In such cases, cold-pressing may be necessary. This of course creates its own problems with respect to adhesive limitations, assembly time, water introduced with adhesive, long time under pressure and, in some cases, durability of the bond. Ordinary cold-setting adhesives, however, are undoubtedly adequate for a host of prospective sandwich-panel applications.

One of the most persistent difficulties in the use of sandwich panels is in the problems caused by the necessity for edges, inserts, and connectors for panels. In some cases, the problem involves tying together thin facing materials without severe stress concentrations and, in other cases, such as furniture, the problem is caused by "show-through" of core or inserts through decorative facings. These problems, probably as much as any other factor, have restricted the development and use of honeycomb core on a larger scale and should be studied from several standpoints. The differential dimensional movement between core and insert materials should be at a minimum, including the rate as well as the degree of movement. Adhesives and moisture introduced by adhesives would be a factor in this study. Examples of materials to consider for edges or inserts would be end-grain wood, plywood on edge, part honeycomb and part wood, metal, dense honeycomb, and mastics or fillers. Another approach would be to study engineering design factors for getting panels into the ultimate product without the use of molded-in inserts; this has certain ideal features from the standpoint of sandwich-panel manufacture, and it simplifies pressing.

Properties of Sandwich Panels

Strength

Strength data were obtained on both large and small sandwich panels comprising paper-honeycomb core with facings of veneer, plywood, hardboard, asbestos board, aluminum, or other materials. These tests included static bending, impact bending, and column tests. The most common test conducted was the static bending test, which consisted of supporting the panels at the ends and applying an increasing load at two quarter-span points. The amount of deflection was recorded at various loads to the design load or until failure occurred. This test not only produced useful information on stresses developed in the facings and on stiffness of the assembly but gave information indicative of the shear strength of the cores and the quality of the bond between core and facings.

In the impact bending test, a 10-inch-diameter sandbag, weighing 60 pounds, was dropped on the center of a large sandwich panel, beginning at a height of 1 foot and increasing by increments of 1 foot to a height of 10 feet or until failure occurred. Panels were supported at each end, and both instantaneous and permanent deflections were measured. The vertical load test was made to determine the ability of a panel to meet certain column structure requirements. The shortening of the panel in the vertical direction and its lateral deflections were measured.

Strength tests conducted on large size sandwich wall panels, 3 inches thick and having plywood facings, indicated higher shear strengths developed in bending and greater resistance to vertical loads than found in conventional house construction. These panels withstood maximum loads in bending of at least 12 times the design loads of 20 pounds per square foot sometimes used for house panels.

A considerable amount of design data has been obtained to make it possible to predict the strength of sandwich panels or to design them to meet certain strength requirements. The core of the sandwich may be considered as only a means of separating and stabilizing the facings to produce a member similar to an I-beam. The core simulates the web and the facing the flanges of an I-beam. Since the core in the sandwich is subjected to shear, as is the web of the I-beam, it is essential that the core be sufficiently strong to withstand the shearing stresses imposed. It is assumed, however, that the core itself adds no stiffness to the sandwich construction.

The following formulas are used for predicting the behavior of sandwich constructions subjected to various loads. No consideration is given to concentrations that may occur at joints and fastenings. Each type of fastening will have to be considered individually insofar as its effectiveness in transmitting loads and its strength are concerned.

The constructions are assumed to be well bonded with an adhesive and strong and durable enough to perform adequately for the conditions of use.

The mean stresses in the facings of sandwich construction under flatwise bending loads are given by

$$\sigma_{1,2} = \frac{2M}{f_{1,2}(h + c)b} \qquad (1)$$

where $\sigma_{1,2}$ = facing stresses in facings 1 or 2
or 2
$f_{1,2}$ = thicknesses of facings 1
M = moment
h = total sandwich thickness
c = core thickness
b = width of sandwich

The shear stress in the core of sandwich construction under bending loads is given by

$$\tau = \frac{2V}{(h + c)b} \qquad (2)$$

where τ = core shear stress
V = shear load

The stiffness of sandwich construction having facings of the same material and equal in thickness is given by

$$D = \frac{E_F(h^3 - c^3)b}{12\lambda} \qquad (3)$$

where D = stiffness
E_F = modulus of elasticity of the facings
$\lambda = 0.99$ for wood or plywood facings
$\lambda = 0.91$ for isotropic facings

The maximum deflection of a sandwich construction having facings of the same material and equal in thickness under a uniformly applied load and simply supported at the ends is given by

$$\Delta = \frac{5Pa^3}{384\,D}\left[1 + \frac{\pi^2\, cfE_F}{2\lambda\, a^2 G_c}\right] \qquad (4)$$

where Δ = maximum deflection
P = total load on the sandwich
G_c = shear modulus of the core material
a = span

Note: An approximation of the deflection may be obtained by neglecting the last term in the brackets in formula 4. This term will be less than 10 percent for most constructions on long spans but may become appreciable for short spans.

Strength data for sandwich panels of various thicknesses and comprising different facings are given in Table 1. Most of the information on the 3-inch-thick panels was obtained by experimentation, while values for the 1- and 2-inch thicknesses were calculated mathematically with the above formulas. Values in the table show that reducing the thickness of the panel from 3 inches to 1 inch would decrease its stiffness 10 to 15 times and decrease the maximum load that it will support 3 to 4 times. To meet a span-deflection ratio of 270 or more under a uniform load of 20 pounds per square foot, a structural sandwich wall panel on a span of 96 inches would have to be more than 2 inches thick if its facings were of ¼-inch Douglas-fir plywood. Certain properties of the honeycomb core may be varied considerably with only a mild deviation in stiffness of the resultant sandwich panel.

Dimensional Stability and Bowing of Panels

In a structure such as a sandwich panel in which two facings are bonded to a core to form an integral panel, any dimensional movement of one facing has an effect on the entire panel. A differential movement of facings causes bowing on an unrestrained panel. If dimensional change of both facings is equal, the length and width dimensions of the panel will increase or decrease, but bowing will not result. This is important for many uses. The problem is chiefly related to the facings because the core does not have enough stiffness to cause bowing of the panel or to cause it to remain flat. Laboratory tests have demonstrated that the dimensional stability of a panel is not affected by the type of core. The magnitude of the bowing effect, however, depends on the thickness of core. The use of dissimilar facings is often desirable from an economic standpoint, yet dimensional instability of facings during panel manufacture or exposure may rule out possible benefits, as indicated earlier in this report.

For many applications, such as integral housing panels or what might be described as conventional prefabricated house panels, bowing is almost always a consideration. During exposures in housing when temperature and relative humidity conditions are approximately equal on both sides of the panel, the panel will remain reasonably stable. As cold weather develops, the moisture content on the inner facing of a hygroscopic material decreases and that of the outer facing increases, causing an outward bow. The effects of winter temperatures produce opposite curvatures. During the summertime, the bowing is less pronounced, since the moisture differential is less. This characteristic bowing pattern has been experienced by producers of stressed-skin, plywood prefabricated panels for many years. Although shrinkage and expansion in plywood with moisture changes is slight, the difference is enough to cause a detectable bow. In wood, hardboard, or other hygroscopic materials, warpage can be attributed to both moisture and temperature differences, while in metal-faced sandwich panels, only temperature differences cause dimensional changes, and these changes are due to thermal expansion or contraction.

In conventional construction, it is desirable to install vapor barriers, usually of asphalt-impregnated paper or metal foil, to block the migration

Table 1.--Stiffness and strength of structural sandwich panels on a 96-inch span[1]

Facings	Panel thickness	Center deflection[2]	Span-deflection ratio[2]	Maximum uniform load	Approximate bowing deflection[3]
	In.	In.		Lb. per sq. ft.	In.
1/4-inch Douglas-fir plywood	3	0.184	521	300	0.38
	2	.453	212	192	.58
	1	2.390	40	82	1.15
Two 1/10-inch Douglas-fir veneers with paper overlay	3	.207	464	269	.....
	2	.483	199	175	.....
	1	2.140	45	85	.....
One 1/8-inch Douglas-fir veneer with paper overlay on each side	3	.169	568	332	.....
	2	.396	242	216	.....
	1	1.810	53	101	.....
1/4-inch tempered hardboard	3	.202	475	344	1.00
	2	.498	193	218	1.50
	1	2.630	36	94	3.00
1/8-inch tempered hardboard	3	.313	306	269	.....
	2	.735	130	176	.....
	1	3.350	29	82	.....

[1] All cores of the cross-corrugated XN type were made from 50-pound paper treated with 15 percent of resin. The core density was 2.5 pounds per cubic foot.

[2] Deflection under a uniform load of 20 pounds per square foot on a span of 96 inches.

[3] Midspan deflection computed from the differential expansion of the two facings obtained by exposure of one facing to a relative humidity of 97 percent, the other to a relative humidity of 30 percent for 30 days.

of vapor to the cold side of a wall. Various experiments were conducted or proposed to improve vapor resistance of sandwich panels, such as bonding of metal foil; blending aluminum flake with resin bonding adhesives; use of plastic vapor barriers between veneers, overlay papers, and special finishes; and, of course, metal or plastic facings. Because added cost is likely, some of these should not be resorted to unless their need has been demonstrated. Panel edges may also be sealed by various methods if this is indicated. As a generalization, the bowing of sandwich panels is probably neither greater nor less than stressed-skin housing panels having similar facings.

In one series of tests of bowing under laboratory conditions, six sandwich panels, each 3 inches thick, were subjected to severe temperature differences to determine their bowing characteristics. Panels approximately 20 by 72 inches were placed in openings between two rooms, one of which was held at a temperature of — 20° F. and the other at + 70° F. The edges of the panels were sealed with aluminum foil to prevent the entrance of moisture. The facings consisted of three-ply, ¼-inch Douglas-fir plywood with and without paper overlay; two-ply, 1/5-inch plywood with paper overlay; and overlaid, ⅛-inch veneer. One of the plywood-faced panels had two coats of aluminum paint on the warm side only.

Al panels deflected slightly toward the warm side immediately after being installed, as the facing on the cold side underwent thermal contraction. As the test progressed, the deflection became less prominent, because the moisture content of the cold side increased. The overlaid, three- and two-ply constructions after 9 weeks' exposure became straight. At the end of the exposure, the overlaid veneer panel showed the greatest deflection, although the overlaid, three-ply panel showed the greatest initial change. After the panels were removed from the wall and exposed to 70° F. on both sides for 3 hours, the panels reversed themselves, bowing toward the cold wall. This was probably caused by the plywood on the cold side undergoing thermal expansion and possibly, in part by the absorption of moisture from the melting of the frost crystals that had formed inside the panels during the exposure. Although these test conditions are not exactly typical of ordinary service conditions, the amount of deflection observed in these panels would not be considered objectionable. Accurate data on the dimensional change of sheet facing materials due to moisture or thermal changes is very important to a study of panel bowing.

Table 2.--Effect of core construction, density, and filler on thermal conductivity of core made from resin-treated paper

Core construction	Filler in core	Density	k	$\frac{1}{k}$
		Lb. per cu. ft.	B.t.u. per hr. per sq. ft. per inch per ° F.	
XN	None	2.75	0.45	2.22
PN	do	2.94	.46	2.17
PN	do	5.47	.58	1.73
PNL	do	3.35	.47	2.13
PNL	do	5.50	.59	1.69
Figure 8	do	2.89	.53	1.89
PN	Foamed resin	5.36	.40	2.50
Figure 8	do	1.88	.31	3.23
PN	Fill insulation	4.72	.37	2.70

It is possible to calculate mathematically the bowing of a sandwich construction if the percent expansion of each facing is known. The maximum deflection due to bowing caused by the expansion of one facing resulting from temperature or moisture differential is given approximately by

$$\Delta = \frac{ka^2}{800h}$$

where k = percent expansion of one facing as compared to the opposite facing
a = length of panel
h = total sandwich thickness

Using this formula, the approximate bowing deflection was calculated for hardboard- and plywood-faced sandwich panels of various thicknesses. This information is given in Table 1. The bowing deflection due to moisture or temperature differences is greatly dependent on thickness of the panel. As an example, a 96-inch-long, plywood-faced panel 3 inches thick bows about one-third as much as a similar panel 1 inch thick.

Thermal Conductivity

The basic values determined in establishing the thermal conductivity of a material or combination of materials used in a structure can be defined as follows:

k — thermal conductivity: The time rate of heat flow through a homogeneous material or one of uniform structure under steady state conditions, expressed in British thermal units per hour per square foot per inch of thickness per degree difference in temperature between surface of the material.

U — over-all coefficient of heat transmission, air to air: The time rate of heat flow expressed in British thermal units per hour per square foot per degree difference in temperature.

The term *U* applies to the combination of materials used in a construction; for example, both facings and core of a sandwich, and includes standard values for f_i and f_o for still air on the warm side and air moving at 15 miles per hour on the cold side.

The usual method of comparing insulating values for wall construction is by comparison of heat transmission coefficients or *U* values. The *U* value for a construction is found from the relation

$$U = \frac{1}{\Sigma \frac{t}{k}}$$

where the values of *k* are for the several constitutents of the wall and *t* the thickness of these constituents.

To compare insulating characteristics of various core constructions, tests were made on 1-inch-thick specimens using a guarded hot-plate apparatus. The data are summarized in Table 2. The conductivity value of the core is affected by: cell size, density, resin content, construction, and type of material. Thermal insulation was significantly affected by the type of construction; values for *k* varied from as low as 0.30 to as high as 0.65 with variations in core structure. A *k* value of 0.45 and 0.46 British thermal units per hour per square foot per

inch of thickness per degree F. was obtained with cross-corrugated (XN) or the parallel-corrugated (PN) structures having flutes perpendicular to facings. By placing these same structures in the test so that flutes were parallel instead of perpendicular to the plates, the value was reduced to 0.30 to 0.35, but these structures have other disadvantages, as mentioned earlier in this report. For any particular core construction, the density of the structure affects the insulation value. As an example, a PNL core having a density of about 5.5 pounds per cubic foot had a *k* value of about 0.59, while a similarly assembled core, with a density of 3.35 pounds per cubic foot, gave a *k* value of about 0.47.

An actual *U* value of 0.150 British thermal units per square foot per hour per degree F. was obtained on a 3-inch-thick, large-size panel having the cross-corrugated (XN) type of core and ¼-inch, three-ply Douglas-fir plywood facings. This panel was exposed in a wall between two rooms, one controlled at 72° F. and 40 percent relative humidity and the other at — 20° F. This 0.150 value compares reasonably well with a calculated *U* value of 0.144 for the same panel. If the thickness of this panel was reduced to 1 inch, the *U* value could be expected to increase to about 0.42.

An improvement in the insulation value of the sandwich construction can be realized by filling the honeycomb core with insulation or a foamed-in-place resin. A reduction in the *k* value of a corrugated core from 0.46 to 0.40 British thermal units per hour per square foot per inch of thickness per degree F. was obtained when a phenolic resin was foamed into the core. A slightly lower value was obtained through the use of fill insulation. Foaming of resins into honeycomb appears very promising as a means of improving thermal insulation and fire resistance.

Fire Resistance

Sandwich panels were tested for fire resistance by two methods designed for housing materials: (1) Exposing one face of the panel to a standard flame that approximates conditions of fire in a house in which furnishings are being burned; and (2) introducing flame through a hole in the facing, as might occur at openings for electrical conduit or other house equipment.

The first method gives fire-resistance values for sandwich construction that are comparable with those accepted for other types of house construction. The critical factor in this test is the ability of the facings and the bond between the facings and core to resist the high temperature without developing construction failures. Obviously when the facings or bond have failed, the construction is gravely weakened, since the facings are the principal load-carrying elements of the sandwich. At the Laboratory, this test was conducted in a gas-fired furnace according to the exposure conditions specified in American Society for Testing Materials (ASTM) Specification No. E–119–47. The fire resistance of the wood-faced sandwich panels was appreciably higher than hollow panels faced with the same thickness of plywood. When aluminum-faced panels were exposed to the gas, a rather rapid buckling of the facing and failure of the bond usually occurred. In most cases, the cores were badly charred after the test but retained their original form to a considerable extent.

The fire resistance of the sandwich panel can be increased considerably by incorporating in the core foamed resin or an intumescent coating material, such as certain types of sodium silicates. It is conceivable that a material could be developed for deposition in the core that would serve the triple function of bonding the paper sheets, providing foam for fire resistance, and also improving thermal insulation.

By the second method, the likelihood of flame spread in the core was investigated. This was done by cutting a small hole in one facing, holding the panel vertically, and applying a gas flame to a small area for 4 minutes. In panels having flutes perpendicular to the facings, such as in the expanded figure-8 and the corrugated PN and PNL types of core, only slight flame spread occurred. Burning was restricted to the honeycomb material in contact with the flame. When the flame was removed, flaming stopped immediately. Some glow persisted for an additional 1 to 2 minutes. In the case of the cross-corrugated XN type of core in which one-half of the flutes are parellel to the length of the panel, the spread of flame occurred in the vertical direction due to the open channels. This could no doubt be readily improved by placing a barrier sheet at the top of the panel or at intervals in the panel height, or perhaps by simply turning the length of the core blocks at 90° to the vertical direction.

The resin-treated core in itself is not fire-resistant, but its use between sandwich facings does not seem to be hazardous. It is possible to add fire-resistant chemicals to the paper or to dip or spray the core assembly with such chemicals, but this is believed to be unnecessary when wood-based facings are employed in the panel construction. Such treatments could be effected, if necessary, but might create gluing and moisture-absorption problems, and their effects on long-time aging characteristics of paper are not well understood.

Sandwich-panel Exterior Test Unit

In 1947, an experimental sandwich unit about 12 by 40 feet in size was built on the Laboratory grounds for long-time exposure tests. Incorporated in this unit are various types of sandwich wall, floor, partition, and roof panels. All have paper-honeycomb cores and are faced with veneer, plywood, overlaid plywood, hardboard, asbestos board, or aluminum for comparative purposes. The unit on the inside is equipped with heating coils and is controlled during the winter at a temperature of 72° F. and a relative humidity of 40 percent. The outside of the unit is exposed to the variable outdoor temperatures of the Madison, Wis., area.

Before the wood-faced and aluminum-faced panels were installed in the test unit, they were tested to determine their deflection and span-deflection ratios at design loads. The 3-inch-thick, wood-faced wall panels met the requirement that the span-deflection ratio be not less than 270 under a design load of 20 pounds per square foot. Floor panels of 6-inch thickness with facings of ⅜-inch, five-ply Douglas-fir plywood had a span-deflection ratio of about 800 under a load of 40 pounds per square foot (11).

After 16 months' exposure, four wall panels were removed from the experimental unit for test. Two panels had facings of ¼-inch Douglas-fir plywood, and two had facings of ⅛-inch Douglas-fir veneer overlaid with paper. Cores were of the cross-corrugated XN type. On removal, the panels showed no visible signs of deterioration in either the core or the facings. The stiffness of the exposed panels was equal to or slightly greater than their stiffness prior to installation. This increase in stiffness may possibly be due to the further cure of the resin upon aging. Maximum loads obtained on these panels varied from 13 to 20 times the design load of 20 pounds per square foot.

To obtain additional information on the effect of continuous weathering on appearance and strength, sandwich panels having 1-inch-thick, paper-honeycomb core and various wood facings with and without paper overlays

were subjected to the following conditions in the Laboratory:

1. Immersed in water at 122° F. for 1 hour.
2. Sprayed with wet steam at 194° to 200° F. for 3 hours.
3. Stored at 10° F. for 20 hours.
4. Heated in dry air at 212° F. for 3 hours.
5. Sprayed with wet steam at 194° to 200° F. for 3 hours.
6. Heated in dry air at 212° F. for 18 hours.

This sequence of exposures was continued through six cycles, after which appearance of the specimens was noted, and bending tests were made to determine any change in strength properties. Results of these tests were compared with those of tests made on control specimens not subjected to the aging tests. The reduction in shear stress developed in the cores of the aged specimens was about 20 to 30 percent as compared with that of the control specimens. Reduction in stiffness was about 20 percent as obtained from a comparison of load-deflection ratios. The sandwich specimens were exceptionally straight, and no visual defects were apparent in the core. Although accelerated aging tests are never completely satisfactory, the performance of such specimens plus the observations made on the actual exposure unit indicate that good performance could be expected.

One of the reasons for building the test unit was to obtain measurements of the actual bowing under outdoor conditions. Some data were obtained during the first year of exposure of these panels. Shortly after the unit was constructed in June 1947, deflection data showed a tendency of the panels with wood facings to bow slightly inward. In November when the heating system was turned on, the wood panels reversed their movement and bowed outward. The outward bowing was due to the lower outside temperature, which caused an increase in moisture content of the outer facing, and the shrinkage of the inner facings due to the heat. The bowing increased progressively in the wood-faced panels as the average outdoor temperature decreased and continued until late in March when the outdoor temperature began to rise again. The maximum bowing recorded in plywood-faced panels was about one-fourth inch. Aluminum-faced panels, not being affected by moisture, bowed toward the inside as the temperature of the outside dropped. On a hot day with a high surface temperature on the outside, an outward bow could be noted. Results of the first year indicated that bowing of sandwich panels with facings of three-ply plywood is consistent with that of panels with three-ply stressed facings. Whether the inner surface was untreated, had aluminum paint, or had an overlay appeared to be unimportant in panels with three-ply facings.

As the development of the sandwich structural panel grows, the need for more data on the behavior of such panels under ordinary exposure conditions will increase. It is hoped that this test unit will be helpful in resolving some of the problems regarding large-scale use of sandwich panels. Although there are many other uses for sandwich panels, the evaluation of these panels under housing conditions provides information that applies to most other products in which use of sandwich panels might be considered.

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Moisture Meters in Industry[1]

JOHN R. BARNES

Executive Vice-President and General Manager, Moisture Register Company, Alhambra, California

DURING the past 15 years, technical research in many industries has definitely identified moisture as a direct source of difficulty in the production and quality control of a wide variety of items. Keeping pace with this research has been the development and improvement of moisture testing instruments. Electrical moisture meters are now acknowledged by many as practical tools which are designed to do a specific job and are not just gadgets to be purchased, used a few times, and placed on the shelf. Let it be plainly understood that these meters are not intended to take the place of standard laboratory testing. They are designed to supplement precise laboratory gear. Because of their speed of operation, moisture meters can make many more tests per man-hour and thus leave only the samples showing doubtful results to be monitored by the slower laboratory procedure. Universal recognition of moisture testers has not yet been quite accomplished. In fact, the use of moisture meters is still a controversial subject in many plants. It seems that users of moisture testers either love them or will have nothing to do with them. This is a healthy condition as it keeps manufacturers of moisture meters on their toes and constantly plugging to improve our products.

The purpose of this paper is to report the progress that has been made in the development of moisture testing instruments since the first portable lumber meter was designed in the late 20's. Since that time, more than ten organizations have designed and placed moisture testers on the market. More than seven of these concerns have produced instruments to serve the lumber and woodworking trades. As the manager of one of these companies, I am proud to report that electrical moisture meters are now well beyond the gadget stage. Our instruments can be trusted to take a definite place among other recognized production and laboratory equipment. It has been a long hard pull and, for most of us in the business, the fight is still on.

For a moment, let me show you a few of the industrial fields that are now being served by moisture meters. You are all familiar with the role these instruments are playing in the lumber and woodworking fields. Instruments of the radio frequency and resistance (needle) types are now being widely used.

[1] Presented at meeting of Forest Products Research Society, Pacific Southwest Section, Los Angeles, California, April 23, 1952.

Where Moisture Meters Serve

They range in size from the Tag Midget and the pocket size DC–1 Moisture Register to the new Laucks Sentry designed for use on moving wood. The meters range in penetration from $\frac{1}{8}$ inch to 2 inches. Lumber moisture testers are used by lumber mills, planing mills, sash and door plants, cabinet shops, veneer and plywood plants, furniture factories, boat builders, building supply dealers, wholesale and retail lumber yards, building contractors, architects, etc. Moisture Register Company now has instruments in the field to determine moisture in wood waste materials, hard board, toilet seats, hammer handles, Dixie spoons, and hot-line tools used by power linemen. In each of these operations a moisture meter is doing a specific job. Thousands of dollars are saved every year in cash and time by the use of a good moisture meter on the job. These operations are not new to you.

Let us, therefore, take a quick look at those other industries in which moisture meters are now being satisfactorily used. If I seem to mention my own instruments, it is only because I am more familiar with their history, and not because they are the only good moisture testers on the market. There are several excellent instruments manufactured by reputable firms. To the best of my knowledge, however, Moisture Register Co. is the only concern currently manufacturing moisture testers serving all these industries.

Take first the paint industry, in which improper moisture in painted surfaces presents a difficult problem. Moisture has become such a problem in the painting industry that such leading publications as the National Painters Magazine, American Painter and Decorator; and the American Paint Journal have published a series of articles on the subject. In the February 1952 issue of American Painter and Decorator is an article entitled "That Moisture Problem", with the subtitle "How Moisture Meters Can Be Used to Help Prevent Paint Failures and Save Money and Grief". On authority of the National Paint, Varnish and Lacquer Manufacturers Association, it was cited that 80 percent of paint failures are due to moisture rather than to paint. Through the use of education, the paint manufacturers and painting contractors are being urged to use moisture meters before painting plaster walls, lumber surfaces, etc. I am very proud to say that Sherwin-Williams Company, at Cleveland, Ohio, worked with our engineers in perfecting our present combination lumber and plaster instrument. After nearly a year of testing, the instrument was finally approved and purchased. Since then we have placed identical meters in the Chicago and Dallas plants of Sherwin-Williams Co., and we have recently quoted on instruments at two additional Sherwin-Williams plants. The scientific department of the National Paint, Varnish and Lacquer Manufacturers' Association in Washington, D. C. also is now using our meter in the field.

Next, take a brief glance at the textile industry. During 1951, more than 200 moisture meters were placed by one company in textile plants throughout the U. S. A., Canada, and foreign countries. Moisture is a real public enemy in this field. From the time the raw materials are brought into the plants until they are finally manufactured into the finished product, a textile superintendent is faced with the problem of moisture. For example, wool and cotton are purchased by the pound and the seller is allowed a certain moisture regain. Naturally the seller wants to be certain he maintains his allowable regain since every pound of water is worth money. Likewise, the buyer must have some quick method of checking moisture content in the materials he buys so that he does not buy water instead of wool. In the manufacturing process it is important to know the moisture content of yarns or threads that are wound on cones or beams.

Quality and tensile strength of yarn are affected by moisture. The amount of yarn wound on a cone is related to the moisture content in the yarn. Suppose you are responsible for the production of sweaters in a knitting plant. You must be able to count on a certain amount of yarn per cone. If certain cones contain more moisture than allowable your sweaters may end up with only one arm, your production schedule is jeopardized, and production costs increased. In other instances it is essential to maintain a certain amount of moisture in the materials.

were subjected to the following conditions in the Laboratory:

1. Immersed in water at 122° F. for 1 hour.
2. Sprayed with wet steam at 194° to 200° F. for 3 hours.
3. Stored at 10° F. for 20 hours.
4. Heated in dry air at 212° F. for 3 hours.
5. Sprayed with wet steam at 194° to 200° F. for 3 hours.
6. Heated in dry air at 212° F. for 18 hours.

This sequence of exposures was continued through six cycles, after which appearance of the specimens was noted, and bending tests were made to determine any change in strength properties. Results of these tests were compared with those of tests made on control specimens not subjected to the aging tests. The reduction in shear stress developed in the cores of the aged specimens was about 20 to 30 percent as compared with that of the control specimens. Reduction in stiffness was about 20 percent as obtained from a comparison of load-deflection ratios. The sandwich specimens were exceptionally straight, and no visual defects were apparent in the core. Although accelerated aging tests are never completely satisfactory, the performance of such specimens plus the observations made on the actual exposure unit indicate that good performance could be expected.

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I am told that over 5,000 stitches are taken in sewing up an ordinary pair of denim jeans. If the thread gets too hot it breaks and fouls up production. Therefore, it is necessary to see that the denim is kept damp during this operation in order to keep the thread cool. Moisture testers are currently being used in this operation to make quick checks on the denim. These are only two examples among hundreds that could be cited to show the utility of quick and accurate means to check moisture in textile materials.

With the development of rayon, nylon, orlon and other synthetics, a full-scale research program for each material has been necessary by the moisture meter manufacturers. Our own company has worked with the Textile Research Institute at Princeton University in the development and evaluation of moisture meters for textiles. Several papers have been published on the subject by the Institute as well as the bulletin regarding the use of our Model PDI on wools, in which the accuracy for the instrument was established at plus or minus .3 percent moisture content. Textile moisture testers are now being used in the production of wool, cotton, rayon, nylon yarns and fabrics, denim, fine suitings, blankets, sheets, towels, band-aids, personal products, etc.

Another field in which we are actively engaged is that of paper and paper products. Here again moisture meters are playing an active role in production and laboratory testing. As with textiles, the instruments are directly calibrated for the specific papers or products tested.

These materials include such common items as kraft papers of all types, paper bags, pulp, bond papers, ledger papers, bread wrap, sensitized papers, citrus wrap, toilet tissue, corrugated boxes, many types of containers, paper plates, cellophane, Dixie cups, roofing felt, offset papers and others. Our company is working closely with the Institute of Paper Chemistry, Lithographic Technical Foundation, and the Technical Association of the Pulp and Paper Industry.

Our portable instruments are being applied in various other fields covering such materials as ceramics, leather products, jute fibers, cork, cut cigarette and leaf tobaccos, etc. When you hear the sales pitch over the air about moisture in tobaccos, don't sell it short. Moisture meters are now being used in the production of many leading cigarettes and cigars.

We have just placed on the market the fifth in a series of large instruments designed for use on powdered and granular materials. This instrument applies hydraulic pressure to the sample in order to compress the granules into a solid cake before the electrode. By means of interchangeable range boxes one instrument can be used to test the moisture content of as many different materials in as many different ranges as desired. Our granular instruments have been applied satisfactorily for use on starches, brewers grits, hops, meals of all types, mild soaps, ground cork, dehydrated foods, certain industrial chemicals, paint pigments and other materials.

Calibration

By this time you must be thinking of the cure-all advertisements for certain patent medicines. This condition is far from true. You can rest assured that each of the several reputable moisture testers on the market today is backed by careful research and development. We realize that our work has just begun. But we are making progress. Again permit me to take our company as an example. Each instrument we sell is carefully calibrated against representative samples in accordance with recognized methods of calibration procedure.

Only last year we completed the recalibration of our standard lumber instruments for more than 60 wood species based on results taken from more than 3,500 samples. In addition to running careful oven determinations, we also ran parallel curves by the susceptance variation method of measuring dielectrics in the woods. It took us nearly two years after the samples were received to cut them into appropriate sizes, condition them in a wood tower to equilibrium and then calibrate the samples by oven and susceptance methods. Sometimes we wonder if it was all worth while when we hear of those "hit and run" oven checks which give accurate results in 20 minutes.

When checking other materials besides lumber, the instruments are virtually calibrated to the customer's application. In addition to the several recognized authorities mentioned previously, our company keeps in close touch with the Forest Products Laboratory, the Forest Products Research Society, and the American Society for Testing Materials. We furnish our equipment to all leading universities where the use of moisture testers in various trades is taught. We are constantly working with schools in special projects. For example, the Yale School of Forestry has been using our equipment for two years in the study and calibration of moisture in foreign woods. This close contact with educational institutions has given us valuable data that would have taken us years to prepare.

One of the most familiar questions asked us is, "Will the results taken with Moisture Register stand up in case of a claim?"

While the purpose of a moisture tester is not to furnish a legal weapon, we can state that Southern Pine Inspection Bureau has used its many Moisture Registers on an average of 1,100 times per year for the past several years in court claims, and the Moisture Register results have stood up.

How to Buy an Instrument

In closing, here are a few simple rules that might be followed when purchasing a moisture meter:

1. Be sure the instrument you buy will do the job you require of it.
2. Look for an instrument with reasonable accuracy. Don't ask for the moon. There are several good instruments to choose from that will give practical satisfaction.
3. Look for speed, portability, and convenience of operation. Time is money these days, so don't waste money in useless effort.
4. Don't buy entirely by price. In the instrument field there is no bargain, and you generally get what you pay for.
5. Purchase from a reputable concern that makes moisture testing its business and is able to back up its claims.
6. If possible, try out the instrument before you buy. Beware of firms who refuse to allow trials.

After purchasing the instrument, use it. If you buy one of the leading moisture testers, you can't go far wrong with it. You have an investment in your instrument and you owe it to yourself to use it. If you have reason to doubt the results of your instrument, contact the manufacturer. He can't correct the situation if he doesn't know about it. In many cases you may have misunderstood the operating instructions, the instrument may have become damaged, or you may have compared results with inferior equipment. At any rate get the instrument back into use, or trade it on equipment that will better meet your application.

An Electrical Test For Decay in Wood[1]

D. B. RICHARDS

Forester, Agricultural Experiment Station, Alabama Polytechnic Institute, Auburn, Alabama

INCIPIENT DECAY can severely weaken wood without noticeably altering its appearance. It is often desirable to detect such decay by a non-destructive test. This is particularly desirable when selecting wood for uses where the presence of weak, decayed wood can have fatal consequences. The study reported in this paper was undertaken to see if the radio frequency electrical properties of wood could be used to detect the presence of decay.

Materials and Methods

All wood samples for this study came from two 6-foot logs, one of loblolly pine, *Pinus taeda L.*, and one of American sweetgum, *Liquidambar styraciflua L.*, commonly called red gum in the trade. Quarter-sawed boards from these logs were kiln dried to 6 percent moisture content and the sapwood portion cut into small beams ½-inch by ½-inch by 6-inches. The beams were brought to equilibrium at 7.7 percent moisture content, weighed, and the original oven-dry weight calculated. For each fungus 56 beams were employed as decay samples.

Four different fungi, two brown rot organisms and two white rot organisms, were used in this study. The brown rot organism, *Poria monticola* Murr., and the white rot organism, *Polyporus abietinus* (Dicks.) Fries, were used to decay the pine samples. The red gum samples were decayed by the brown rot organism, *Lenzites trabea* (Pers.) Fries, and the white rot organism, *Polyporus versicolor* (L.) Fries.

The beams were steamed 5 minutes at atmospheric pressure and then placed in the appropriate decay chambers. The decay chambers contained pure cultures of the fungi growing on malt agar substrata. They were kept in a darkened room that was maintained at 80° F. and 80 percent relative humidity. At total of 32 beams was removed from the decay chambers at the end of each 2-week period up a total of 14 weeks. These 32 beams (8 for each fungus) were immediately tested electrically.

The electrical measurements were all made at a frequency of 5 megacycles per second on a Boonton Q-meter model 160A. The test beams were inserted as the dielectric material of a test condenser that was held firmly against the wood beam by means of a jig made from a 9-inch C-clamp (Fig. 1). Since the bottom plate of the condenser was at ground potential, no special care was taken to separate it from the C-clamp by a large distance. The bottom plate of the condenser with its soldered lead was fastened to a piece of dry wood to lend it stiffness. This wooden stiffener was notched to fit over the fixed jaw of the C-clamp. The upper plate, which was at a raised potential, was separated from the side of the clamp by a 2.5 inch air gap, and from the screw head by 3.5 inches of kiln-dried basswood. Both plates of the condenser presented a flat polished surface to the wood and were of such a size as to just cover the wood samples to be teseed when they were in a wet condition.

A test piece after having been removed from the decay chamber, was wiped clean of adhering fungus mycelium, placed between the condenser plates with the radial surfaces of the wood against the plates, and the screw turned up firmly to insure complete contact of the plates. In this position the current flowed in a tangential direction through the wood. The Q-meter was turned to resonance and the readings of the Q scale and the tuning capacitance were recorded as Q_2 and C_2 respectively *(2)*.[2]

Immediately after being tested electrically, each piece was weighed and the dimensions measured; the piece was then oven dried and re-weighed. From the above data the percent moisture at test, specific gravity, percent weight-loss due to decay, dielectric constant, and conductivity were calculated. The relationships were then studied by multiple and partial regression analyses.

In addition to the decayed samples, undecayed control pieces of loblolly pine and red gum were tested electrically throughout the moisture ranges exhibited by the decayed samples.

Calculations

The moisture content of each beam at time of testing was expressed as a percentage of the oven-dry weight of the decayed wood.

Specific gravity at time of testing was calculated on the basis of the oven-dry weight and the wet volume of the decayed wood.

The weight-loss due to decay was expressed as a percentage of the original, calculated, oven-dry weight (prior to decay).

The radio frequency electrical properties determined where the dielectric constant, the quantity Q, and the conductivity in micro-mhos per centimeter.

The dielectric constant of a material is defined as the ratio of the capacitance of a condenser with the material as the dielectric to the capacitance of a like condenser having a vacuum for the dielectric *(8)*. In actual practice an air condenser can be substituted for the vacuum condenser with little change in value. For a given condenser, the dielectric constant, K, of wood can be expressed by the following formula:

$$\frac{\text{Capacitance with wood}}{\text{Capacitance with air}} = K \quad \text{---} \quad 1$$

The quantity Q in a parallel circuit is defined as the ratio of the equivalent parallel resistance to the reactance *(9)*. This quantity Q is not ordinarily used as such, but is very useful in calculating the conductivity.

The resistivity is the proportionality constant that relates the total resistance of a body to its dimensions.

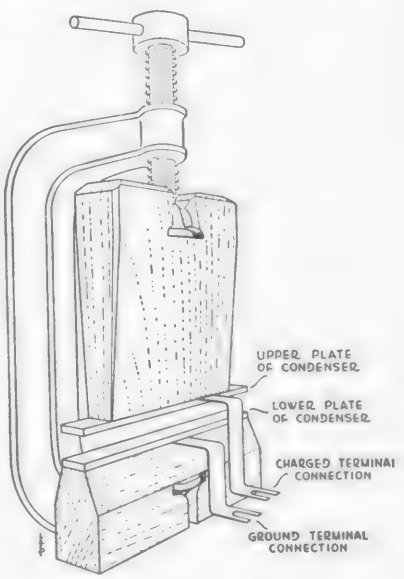

Fig. 1.—A diagrammatic view of the jig used in holding the test beams for electrical measurements. The two horizontal strips form the plates of the condenser in which the beams were measured. The lower plate was at ground potential. The upper plate was at a raised potential. The two forked leads connect directly to the Q-meter binding posts.

[1] A contributed paper to the Journal of the Forest Products Research Society. The laboratory data for this study were part of a doctorate thesis at the N. Y. State College of Forestry, prepared under the supervision of Dr. R. A. Zabel and Dr. R. R. Hirt.

[2] Numbers in parentheses refer to references cited at the end of this paper.

The resistance of a body is proportional to its length and inversely proportional to its sectional area *(8)*.

$$R = r\frac{d}{a} \quad \text{---------- 2}$$

The conductivity is the reciprocal of the resistivity hence

$$c = \frac{d}{RA} \quad \text{---------- 3}$$

A = Sectional area in sq. cm. at right angles to current flow.
c = Conductivity in mhos per cm.
d = Length parallel to current flow (distance between plates) in cm.
R = Resistance in ohms.
r = Resistivity in ohm cm.

The beams used in this study were rather ill-designed for electrical measurements, their shape being dictated by another part of this overall study that involved strength tests. The shape of the samples meant that there was considerable edge effect around the condenser as well as stray capacitance from the high potential side of the condenser to the clamp and certain other stray effects. The total of all such stray effects was measured by taking the difference between the measured capacitance of the empty jig and the theoretical capacitance of the test condenser with air as the dielectric. This stray effect amounted to about 5 micro-micro-farads and was subtracted from all measured test capacitances to yield the true capaciance of the wood, C_x. When the theoretical air capacitance (the length times the width of the plates divided by 11.3 times the distance between the plates) *(9)* is substituted in equation 1, the following equation is obtained for calculating the dielectric constant:

$$K = \frac{11.3\ dC_x}{lw} \quad \text{---------- 4}$$

C_x = Capacitance of the test sample in micro-micro-farads
d = Depth of wood (distance between plates) in cm.
l = Length of wood in cm.
w = Width of wood in cm.

In calculating the quantity Q for the sample both the Q_2 reading (taken with the test piece in place) and the Q_1 reading (taken with air as the dielectric) were employed *(2)*. By a series of calculations it can be shown that the Q of a sample, Q_x, is as follows *(2, 9)*:

$$Q_x = \frac{C_x Q_1 Q_2}{C_1(Q_1 - Q_2)} \quad \text{---------- 5}$$

Although the conductivity can be calculated directly from the Q-meter readings and the dimensions of the piece *(2)*, it is somewhat easier if Q_x and the dielectric constant have been calculated to use the following equation *(9)*:

$$c = \frac{fK}{1.8\ Q_x} \quad \text{---------- 6}$$

c = Conductivity in micro-mhos per cm.
f = Frequency in megacycles per second
K = Dielectric constant
Q_x = Q of test sample

At the higher moisture contents of the wood, the Q-meter readings become unreliable, particularly for conductivity calculations. For this reason all pieces with moisture contents over 40 percent were eliminated from the conductivity studies, and those with moisture contents above 58 percent were eliminated from the study of dielectric constant. The *L. trabea* samples were so high in moisture content that the above criteria left too few samples for effective analysis; therefore, the *L. trabea* samples were eliminated from this study.

The statistical analysis was carried out by means of multiple and partial regression analyses *(1, 5, 10)* by assuming that the electrical property under consideration was the dependent variable and that the percent moisture, the specific gravity, and the weight-loss due to decay were the independent variables. Short-cut graphic approximation analyses *(6)* were first run on the data. In only one case was there any noticeable trend toward curvilinearity, so the assumption was made that the relationships were essentially linear throughout the ranges studied. Based on this assumption a linear multiple and partial regression analysis was made of the data *(5, 10)* and the significance tested.

Results

The conductivity of the wood bore a significant relationship to the amount of decay by the three fungi, (Table 1), but for only one of the fungi studied did the dielectric constant of the decayed wood show a significant relationship to the amount of decay (Table 2). When the units and ranges of the independent variables are considered, it is apparent that the moisture content of the wood has the most important effect on the electrical properties. In general, the total range through which the moisture content varied (Tables 1 and 2) influenced the electrical properties about 1½ times as much as did variation through the range of the next most important independent variable.

The fungi differed to some extent in the manner in which they affected the electrical properties of the wood. For example, the partial regression coefficient of conductivity on percent moisture for *Porea monticola* ($b_{12.34} = 0.647$) was very significantly lower than the like coefficients for *P. abietinus* ($b_{12.34} = 1.48$) and *P. versicolor* ($b_{12.34} = 1.39$).

In addition P. monticola was the only fungus for which percent weight-loss had a significant effect on dielectric constant and the only one for which specific gravity had a significant effect on conductivity.

The mild irregularities caused by *P. monticola* are not large enough, however, to preclude the use of the electrical properties of the wood as a test for the presence of decay. The conductivity of wood is increased by decay but little affected by specific gravity, while the dielectric constant is reduced by a decrease in specific gravity but is little affected by decay. This means that a piece of decayed wood has an abnormally high conductivity due to the decay and a somewhat subnormal dielectric constant due to the reduction in specific gravity that the decay causes. This information suggests that some measure of the difference between the conductivity and the dielectric constant might be a test for the combined effect of decay and low specific gravity. Since the moisture content has such a large effect on both electrical properties, it seems logical to remove this effect by using some form of moisture meter.

When the regression equations for the control pieces (Tables 1 and 2) are averaged and solved for the moisture percent, the following equations are obtained.

$$M_c = 1.52c + 4.26X_3 + 18.8$$
$$M_k = 3.65K + 81.0X_3 + 38.4$$

c = Conductivity of the wood in micro-mhos per cm.
K = Dielectric constant of the wood.
M_c = Percent moisture calculated from the conductivity.
M_k = Percent moisture calculated from the dielectric constant.
X_3 = Specific gravity of the wood.

Using these as calibration equations, the Q-meter can be used as either a radio frequency conductivity moisture meter or as a dielectric constant moisture meter. In order to use these calibration equations, it is necessary to know the specific gravity of the wood. In using a moisture meter in actual practice, the specific gravity of the wood is usually not known hence it is the general practice to apply an average correction for the species of wood in question. Since the pine controls averaged 0.48 and the gum controls averaged 0.43 specific gravity, the following calibration equations can be obtained directly from the preced-

TABLE 1. THE RELATIONSHIP OF THE CONDUCTIVITY OF DECAYED WOOD TO MOISTURE CONTENT, SPECIFIC GRAVITY, AND PERCENT WEIGHT-LOSS DUE TO DECAY

Item			Constants of the multiple regression equation[a] $X_1 = b_{12.34}X_2 + b_{13.24}X_3 + b_{14.23}X_4 + A$				The ranges through which the independent variables were studied[a]		
Wood	Fungus causing the decay	Number of test pieces	$b_{12.34}$	$b_{13.24}$	$b_{14.23}$	A	X_2	X_3	X_4
Loblolly pine	Undecayed Controls	20	0.634**	-15.52		-5.20	28-40	.44-.55	
Loblolly pine	Poria monticola	36	0.647**	28.0*	0.478**	-23.4	29-40	.42-.52	0-10
Loblolly pine	Polyporus abietinus	56	1.48**	14.7	0.374**	-43.0	28-36	.40-.53	0-15
Red gum	Undecayed controls	19	0.681**	9.92		-19.56	28-40	.40-.47	
Red gum	Polyporus versicolor	48	1.39**	32.0	0.218**	-50.8	32-40	.33-.45	1-20

[a] Standard symbolism (5, 10) is used for the regression coefficients and the independent variables. The meaning of the symbols is as follows:
X_1 is the conductivity of the wood in micro-mhos per centimeter measured at 5 megacycles per second.
X_2 is the percent moisture of the wood based on the oven-dry weight.
X_3 is the specific gravity of the wood based on oven-dry weight and wet volume.
X_4 is the percent weight-loss due to decay based on original oven-dry weight.
A is the constant term of the multiple regression equation.

* Significant at the 5% level (10).
** Significant at the 1% level (10).

TABLE 2. THE RELATIONSHIP OF THE DIELECTRIC CONSTANT OF DECAYED WOOD TO MOISTURE CONTENT, SPECIFIC GRAVITY, AND PERCENT WEIGHT-LOSS DUE TO DECAY

Item			Constants of the multiple regression equation[a] $X_1 = b_{12.34}X_2 + b_{13.24}X_3 + b_{14.23}X_4 + A$				The ranges through which the independent variables were studied[a]		
Wood	Fungus causing the decay	Number of test pieces	$b_{12.34}$	$b_{13.24}$	$b_{14.23}$	A	X_2	X_3	X_4
Loblolly pine	Undecayed controls	33	0.310**	25.0**		-12.4	28-51	.44-.55	
Loblolly pine	Poria monticola	52	0.330**	31.8**	0.072**	-16.1	29-56	.35-.52	0-30
Loblolly pine	Polyporus abietinus	56	0.399**	16.3**	-0.026	-10.6	28-36	.40-.53	0-15
Red gum	Undecayed controls	35	0.238**	19.4**		-8.6	28-57	.40-.47	
Red gum	Polyporus versicolor	52	0.292**	17.7**	0.012	-10.6	32-58	.29-.45	1-33

[a] Standard symbolism (5, 10) is used for the regression coefficients and the independent variables. The meaning of the symbols is as follows:
X_1 is the dielectric constant of the wood measured at 5 megacycles per second.
X_2 is the percent moisture of the wood based on the oven-dry weight.
X_3 is the specific gravity of the wood based on oven-dry weight and wet volume.
X_4 is the percent weight-loss due to decay based on original oven-dry weight.
A is the constant term of the multiple regression equation.

* Significant at the 5% level (10).
** Significant at the 1% level (10).

ing ones by substituting these values for the specific gravity:

Red gum wood
$M_c = 1.52c + 20.63$
$M_k = 3.65K + 3.6$
Loblolly pine wood
$M_c = 1.52c + 20.84$
$M_k = 3.65K - 0.5$

Using the above average calibration curves, the Q-meter was used as two different moisture meters and each piece of wood then yielded two moisture meter readings, a conductivity meter reading (M_c) and a dielectric constant meter reading (M_k). On the decayed samples the M_c values were consistently larger than the M_k values due to the fact that the decayed samples had abnormally high conductivities. This relationship shows very strongly when the difference between the moisture meter readings ($D = M_c - M_k$) is plotted against X_4, the percent weight-loss due to decay (Figure 2). All three of the regression equations showed highly significant regression coefficients.

$D = 1.02X_4 + 1.02$
-----*P. monticola* on loblolly pine
$D = 1.01X_4 + 0.40$
-----*P. abietinus* on loblolly pine
$D = 0.53X_4 + 3.33$
-----*P. versicolor* on red gum

The data are consistent enough to suggest the possibility of using two carefully calibrated moisture meters (one a dielectric constant type and one a radio frequency conductivity type) to test for decay.

In the moisture range of this study a difference in moisture meter readings of 3 percent moisture could be used as a rejection level if pieces were being screened for the presence of decay. In this study such a level would reject 77 percent of the pieces that had been exposed to decay organisms and would reject less than 6 percent of the controls that were not exposed to decay. Of the 4 control pieces rejected by this criterion only one was of average specific gravity and the other 3 were below average in specific gravity. Of the 32 decay samples that would be accepted by the above rejection criterion, 12 showed no weight-loss due to decay, 8 showed only 1 percent weight-loss due to decay, 7 showed 2 percent weight-loss due to decay, 3 showed 3 percent weight-loss due to decay and only 2 showed 4 percent weight-loss due to decay (Figure 2). It seems evident from this that those pieces not rejected by the above criterion were decayed very little if at all even though they had been exposed to attack by decay organisms. While only a 77 percent success in rejecting decayed wood may not seem phenomenal, it should be noted that this is a tremendous improvement over visual inspection since none of the decayed samples showed any signs of decay that could be identified positively by a superficial visual inspection.

Discussions and Conclusions

Wood is evidently affected in some manner by decay so as to increase the electrical conductivity. Microscopic examination revealed abundant hyphae in the severely decayed wood. As living protoplasm is generally a good conductor of electricity, the increased conductivity might be caused in some measure by the increased concentration of hyphal strands in the most severely decayed wood. Fungi often produce organic acids *(4, 12)* which would also tend to increase the conductivity of the wood. It is not clear whether or not the hydrolysis and hence shortening of the cellulose molecule has an appreciable effect on conductivity, although it may have a minor effect.

No generalization can be made concerning the relationship between decay and conductivity of wood at other frequencies or for direct current. However, it should be noted that, if the same relationship does hold, conductivity type moisture meters would overestimate the moisture content of decayed wood at least in the range of moisture contents covered by this study.

The dielectric constant was affected by decay only in the case of *P. monticola.* Just why this should be is not clear, nor is it clear why only wood decayed by this same fungus should show a significant relationship between specific gravity and conductivity. These irregularities perhaps serve to emphasize the fact that fungi differ in their physiological activity. It is often misleading to generalize about all fungi on the basis of the activity of a few.

While an electrical method of testing for presence of decay is suggested, such a technique should not be applied blindly without further study of such factors as the effect of different fungi, different moisture contents and different types and frequencies of moisture meters.

The ability of two moisture meters to stay in calibration on normal undecayed wood should also be studied. The relationship between strength and electrical testing should receive special attention since certain strength properties, particularly toughness, may be greatly reduced by so little as 1 or 2 percent weight-loss due to decay and

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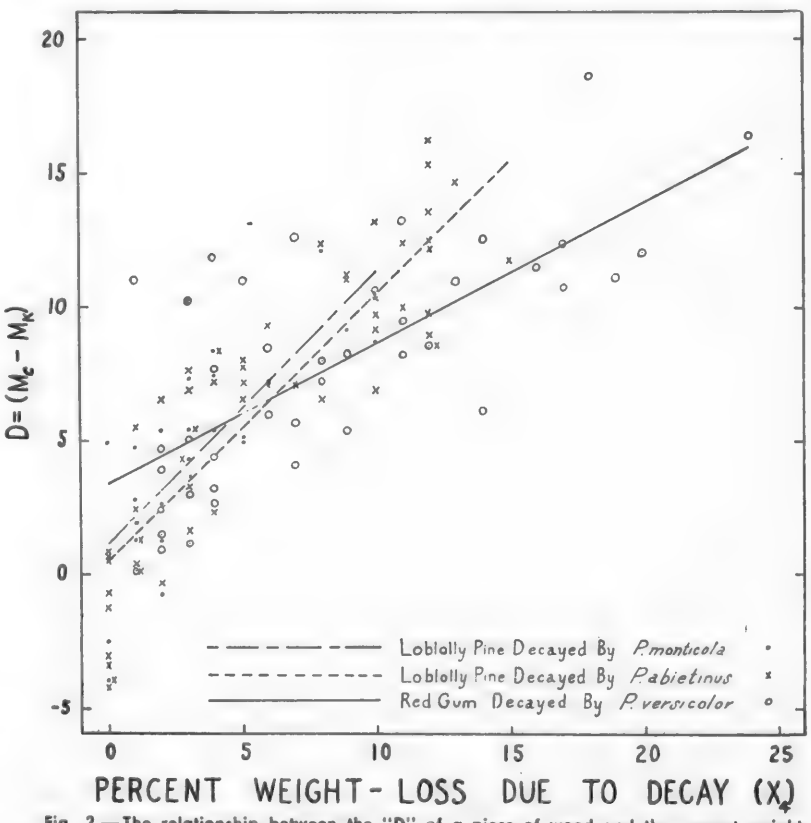

Fig. 2.—The relationship between the "D" of a piece of wood and the percent weight-loss due to decay. The linear regression lines are the lines of best fit by a least squares analysis. "D" is equal to M_c minus M_k where M_c and M_k are the percent moisture of the wood calculated from the conductivity and from the dielectric constant respectively.

Radio Frequency Burning in Glue Joints[1]

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THIS STUDY was undertaken to determine, if possible, the factors causing radio frequency burning in edge-glued joints. The beliefs that such internal burning may be due to (1) pH of the glue and (2) formation of superheated steam in the glue line have been advanced in the past. However, the results of this study indicate that the initiating factor is the development of high dielectric stress due to discontinuities or distortions in an otherwise uniform glue film. The primary cause of these irregularities is resident in the surface characteristics of the wood due to machining or anatomical features.

Introduction

The curing of glue joints by means of radio frequency heating has not been without its attendant difficulties. However, most of the sources of trouble, both mechanical and electrical, have been analyzed and placed under control. As a consequence, this relatively new tool has provided the woodworking industry with a means of obtaining various glued constructions at a high level of production and a high quality of bond.

One factor which has, however, caused some trouble has been the internal burning which occurs in a glue joint, especially during an edge-gluing operation. This type of burning has been experienced rather widely in the industry, and in one or two instances has been the reason for discontinuing an r.f. edge-gluing process. At the College of Forestry, State University of New York, as part of a general project entitled "Wood Gluing Studies", an investigation has been made of this phenomenon.

The internal burning to be discussed in this paper differs considerably from the type of dielectric breakdown known as an arc. As shown in Figure 1, A the ordinary arc has a dendritic or tree-like appearance and usually is initiated at either the top or bottom edges of the glue joint. The carbonized area may spread out along the grain and often will extend from the top edge to the bottom of a glue joint. In this way a highly conductive path is set up parallel to the electric field between the top and bottom electrodes of the edge-gluing press. When this occurs, a sustained arc results which causes the r.f. generator overload relay to kick-out and the panel containing the arc-through must be removed from the press in order to resume operation.

In contrast, an r.f. burn (Fig. 1, B) usually shows a linear pattern, and the results of this investigation indicate that its point of initiation is largely determined by the surface characteristics of the wood at the interface of the glue joint. The burn shows as a carbonized line extending more or less along the grain of the wood and at right angles to the electric field between the press electrodes. The severity of an r.f. burn may be of sufficient magnitude to cause the generator to overload. However, it is more likely that a burn will occur without such an obvious indication of its existence. Since there is no adhesion in the carbonized regions, decrease in the bond strength of the glue joint is inevitable. Consequently, this type of burning must be kept to a minimum, if not prevented entirely, in order to insure maximum strength and durability to a glue joint in service.

Theory of Burning

In a simplified form (see Fig. 2, A) a glue line may be considered to be a pure resistance whose value is dependent upon the conductivity of the glue and the dimensions of the glue line. The voltage drop across such a glue line will be uniform if the glue mix and spread is homogeneous and the edge joints of the wood are parallel[2]. If, however, for any reason a discontinuity or distortion exists in the uniform nature of the glue film, an area of high dielectric stress (high resistance) may be established as shown in Fig. 2, B. A division of the impressed voltage will occur in direct proportion to the resistances in series in the glue line. Consequently, a high voltage may appear across a rather short distance, and an exceedingly high voltage gradient will be established which will induce arcing or burning in the glue line in the region of discontinuity. The fact that burning usually occurs along the grain in a glue line has previously been ascribed to the development of superheated steam which causes the burning, especially along the grain since that is the direction of least physical resistance to its escape from the glue line. In the view of this new theory, the burning occurs along the grain due to the fact that the irregularities on the wood surfaces which give rise to these regions of high dielectric stress are usually more or less parallel to the grain and perpendicular to the electric field, thus enabling a maximum breakdown gradient to be established.

By conventional electrical theory the voltage drop across a uniform glue film is simply

$$E = I_g \cdot R_g \text{ volts} \qquad (1)$$

where E is the impressed r.f. voltage across the wood-glue load, I_g is the effective heating current through the glue line and R_g is the effective parallel resistance of the glue film.

The presence of a discontinuity or distortion in the glue film sets up a region of high resistance, R_d of Figure 2, B, in series with R_{g1} and R_{g2}, the resistances of the uniform portions of the glue film. This results in the series voltage division shown in Figure 2, C. The voltage which appears across R_d is then the total impressed r.f. voltage E minus the voltage drops across R_{g1} and R_{g2}, i.e.,

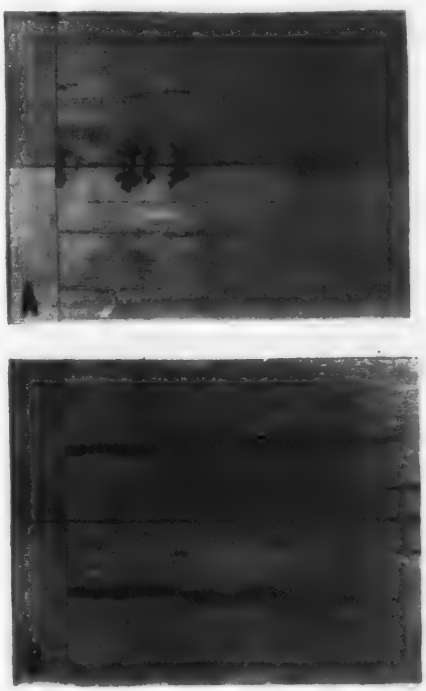


Figure 1.—A, radio frequency arcing in basswood at 1,500 volts per inch. B, radio frequency burning in basswood at 1,500 volts per inch.

[1] A contributed paper to the Journal of the Forest Products Research Society.

[2] Winlund, E. S. 1950. How to boost r.f. gluing production; edge-gluing and end-gluing. Proceedings of the Forest Products Research Society.

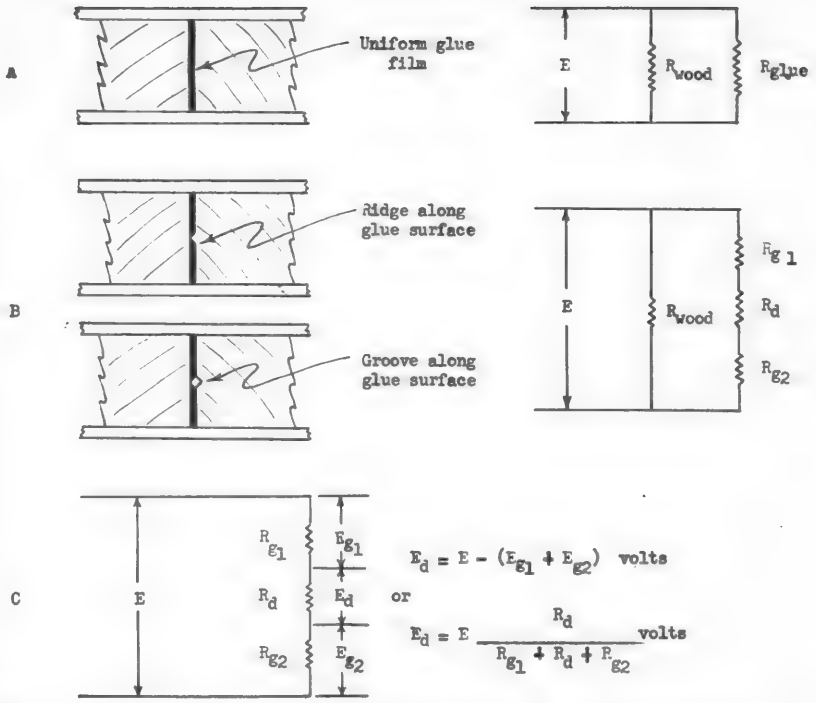


Figure 2.—A, simplified equivalent circuit for an edge-glued joint. B, equivalent resistance of a ridge or groove along joint. C, voltage divison set up by surface regularity.

$$E_d = E(E_{g1} + E_{g2}) \text{ volts} \quad (2)$$

or

$$E_d = E \cdot \frac{Rd}{R_{g1} + R_d + R_{g2}} \text{volts} \quad (3)$$

Since R_d will be much greater than R_{g1} or R_{g2}, a correspondingly high percentage of the total impressed r.f. voltage will appear across R_d. In addition, since the dielectric region is very likely to be quite narrow, the voltage gradient in terms of volts per inch may be from 10 to 100 times the voltage across the press electrodes. It is not surprising then that the wood-glue interface in the region of high resistance may undergo dielectric breakdown which results in the initiating of an r.f. burn.

Causes of Burning

For the purposes of the present investigation an arbitrary breakdown of some of the possible causes of burning was made. The first group consisting of the process variables which may be controlled within certain limits during an edge-gluing operation, were as follows:

1. R.f. voltage gradient across the electrodes
2. R.f. conductivity of the wet glue mix
3. Filler and extender materials in the glue mix
4. Glue spread in pounds per MSGL (thousand square feet single glue line surface)
5. Edge pressure applied by press
6. Duration of heating time
7. Operating frequency of r.f. generator.

The second group of factors consisted of those properties inherent to the wood:

1. Anatomical features of the wood surfaces
2. Machining irregularities on the wood surfaces
3. Water soluble extractives in the wood.

Since oak is one of the species of wood reported by industry as being prone to burn, the initial phase of this study was concerned with an investigation of several of these factors as applied to the r.f. edge-gluing of red oak. A series of edge-glued joints (see Fig. 3) was made under the following conditions:

1. Glue mix and conductivity:[3]
   Glue A: Liquid urea resin adhesive. Approximately 10 per cent of the total mix was walnut shell flour incorporated in the hardener by the manufacturer. R.f. conductivity = 1,200 micromhos per centimeter at one-hour mix age.
   Glue B: Liquid urea resin adhesive. About 7 percent of the total mix was an inert mineral filler incorporated in the hardener by the manufacturer. R.f. conductivity = 3,600 micromhos per centimeter at one hour mix age.
   Glue C: Same liquid resin adhesive as B above but with 5 percent by weight of walnut shell flour added in addition to the regular powdered hardener. R.f. conductivity = 3,000 micromhos per centimeter at one-hour mix age.
2. Glue spread: 30, 40 and 50 pounds per MSGL.
3. Edge pressure: 100, 200 and 300 psi.
4. R.f. voltage gradient: 2,000, 2,500 and 3,000 volts/inch.
5. Duration of r.f. heating cycle: One minute in all runs.
6. Operating frequency: 5.0 megacycles per second.

After removal from the electronic press, the 36-inch long assemblies were sawn into 2-inch blocks as shown in Figure 3. These small blocks were then broken open and the cured glue joints examined. It may be pertinent to point out that the glue joints often showed a high percentage of wood failure. It was therefore necessary to remove the remnants of wood adhering at the glue line in an effort to locate the rather small burns which are initiated at the wood-glue interface. It is quite possible that some of these "incipient" burns may have been passed over or lost when the joint was opened. The results were analyzed in terms of (1) the frequency of burning based on the number of 36-inch-long glue joints which showed a burn at any point along the glue line, and (2) the intensity of burning within any one of the 36-inch-long edge-glued joints. This intensity rating was

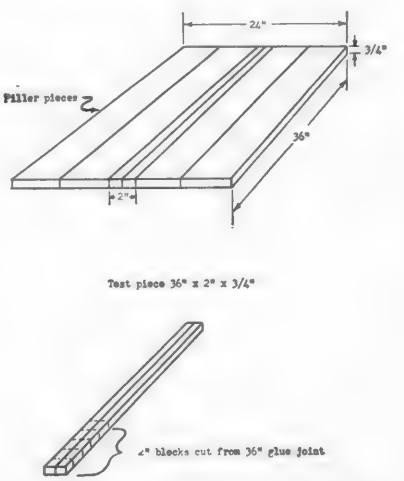


Figure 3.—Lay-up of test joint in press and method of cutting 2-inch blocks which were broken open and examined for burning.

[3] The r.f. conductivity was determined at 5.0 megacycles employing a procedure described elsewhere[4]. The mix age of the glue in all test runs varied from one-half hour to one and one-half hours. Preliminary runs indicated that the slight decrease in conductivity which occurred over this range in mix age had no effect on the test results.

[4] Yavorsky, J. M. 1950. R.f. properties of resin adhesives. Wood 5 (11): 22–23.

based on the number of burned 2-inch blocks cut from the 36-inch-long glue joints.

As shown in Figs. 4 and 5, and as revealed by a statistical analysis employing a Chi-square technique, the r.f. voltage gradient was the only operational variable which had a significant effect on the frequency of burning. In contrast, the intensity of burning was significantly affected by the glue spread and glue characteristics as well as the r.f. voltage. The fact that the low-conductivity glue showed a greater frequency of burning (not, however, significantly greater from a statistical standpoint) than the higher-conductivity glues is somewhat at variance with electrical theory. As indicated by Equation 3, due to the higher values of R_{g1} and R_{g2} for the lower conductivity glue, the voltage division which occurs results in a lower value of E_d so that burning should be less likely. However, the presense of the walnut-shell flour may exert an influence which masks the electrical effect. Figure 5 indicates that the intensity of burning increases with an increase in percent of walnut-shell flour in the glue mix. This is in agreement with the findings of Diamond,[5] Thomas[6] and others. Data to be subsequently presented will show that an increase in conductivity in Glue A increases the burning tendency so that the electrical theory as well as the above reasoning remains tenable.

No attempt was made to investigate the effect of the wood surface on burning in so far as machining characteristics were concerned. All surfaces were smoothly jointed just prior to gluing. However, an examination was made of the cured joints under a low-power (10X) magnification in order to ascertain if any of the anatomical features of red oak served as focal points for burning. At first it appeared that the ray tissue, particularly on a tangential glue face, showed a greater tendency toward burning. However, in the long run it became equally apparent that burns along the spring- and summerwood pores as well as in the denser summerwood tissue occurred in a seemingly random fashion and with the same frequency as burns in the ray areas.

An effort was also made to determine whether the water-soluble extractives in red oak had any effect on burning. A series of samples ½ inch by ¾ inch by 3½ inches were extracted by boiling in water under a vacuum for 6 hours. They were then dried in an oven at 140° F. and finally conditioned to an equilibrium moisture content of 8 percent. Along with an equal number of control pieces cut from the same board, these samples were edge-glued at 3,000 r.f. volts and 200 psi. edge pressure. Preliminary runs were made with distilled water and tap water spread on the edge faces. The only effect of the high voltage field was to dry the surfaces. No burning occurred. Equal areas along the glue face were spread at approximately 40 pounds MSGL with the three glue mixes under study. There was no significant difference in the frequency or intensity of burning between the extracted and the regular oak samples in this limited study.

Another investigation made at this time was an examination of the burning characteristics of the liquid glues with and without the respective hardeners added to the mixes. In addition, based on manufacturing data of the solids content of the uncatalyzed resin glues, a corresponding amount of water was used as a solvating or dispersing medium for the low conductivity glue hardener, the high conductivity glue hardener with and without walnut-shell flour, and for the walnut-shell flour alone. A series of edge joints were then heated employing the several combinations of voltage and edge pressure used in the main study of burning in oak. When the joints were opened and examined, no burning was noted for the uncatalyzed resins or for the walnut-flour dispersion, nor was a bond effected. The catalyzed resin mixes resulted in burns similar in form and number to those obtained in the main study. However, the edge joints spread with the solutions or dispersions of the hardeners showed burns in every case. Moreover, on several occasions when the edge pressure was not applied, actual arcing occurred in the glue lines. Apparently, an unrestricted surface conductivity occurred which resulted in a dielectric breakdown similar to that encountered by Bruce[7] and Thomas.[6] The effects of a lumpy mix were also examined at this time. Several globules of poorly dispersed hardener or filler material were purposely placed in the glue lines. The burning which occurred did not appear to be associated with these imperfections.

[5] Diamond, L. E. 1948. Glues for use with high-frequency heating. Proceedings of the Forest Products Research Society.

[6] Thomas, D. P. 1947. The effect of a catalytic accelerator on dielectric rupture. M.S. Thesis. University of Washington.

[7] Bruce, H. D. 1947. Glues for radio frequency operations. Proceedings: Conference on radio frequency and its applications in gluing wood. University of Washington Bulletin No. 2.

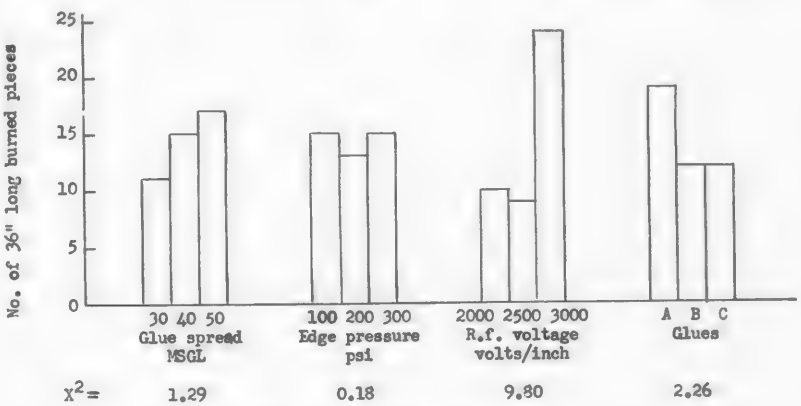
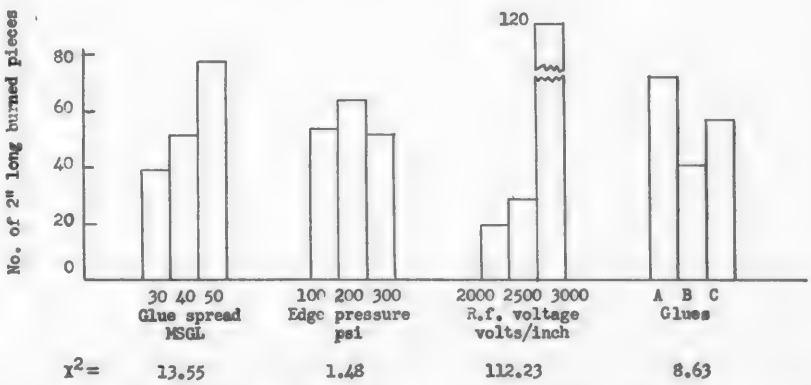


Figure 4.—Frequency of burning in oak.



Note: A Chi-square (X^2) value of 5.99 or more indicates a significant difference to exist at the 5 per cent level in either the frequency or intensity of burning.

Figure 5.—Intensity of burning in oak.

Effects of Wood Surfaces on Burning

The second phase of this study was concerned with the effects on burning of surface irregularities due to wood anatomy or machining. It was also desired to explore further the factors of r.f. voltage gradient and glue conductivity. Two species of diffuse porous wood having rather uniform and fine texture were employed, basswood, *Tilia americana, L.,* and hard maple, *Acer saccharum, Marsh.*

The surfaces examined from a machining viewpoint were:

1. Smoothly jointed surface.
2. Jointed surface with ridge approximately 0.06 inches wide and 0.001 inches high extending along the grain of the gluing surface.
3. Smoothly rip-sawn surface.

The anatomy features investigated were:

1. The effect of the terminal region of dense fibers which sharply delineates the annual rings of the woods under test.
2. The effect of a springwood vessel or pore of a ring-porous wood simulated by cutting a groove varying from 0.028 inches to 0.043 inches wide along the grain of the gluing surface.

Other pertinent factors either controlled or under investigation were:

1. Glue mix and conductivity:
   Mix No. 1: Glue A with mix ratio of 100 parts liquid resin to 12 parts hardener. R.f. conductivity = 1,800 micromhos per centimer.
   Mix No. 2: Glue A with mix ratio of 100 parts resin, 12 parts hardener, 2 parts sodium chloride. R.f. conductivity = 1,800 micromhos per centimeter.
2. R.f. voltage gradient: 750, 1,000, 1,500, 2,000 and 2,500 volts per inch.
3. Edge pressures: Basswood: 100 and 200 psi.
   hard maple: 150, 250 and 350 psi.
4. Glue spread: 40 pounds MSGL in all cases.
5. Heating period: Basswood: 30 and 60 seconds.
   hard maple: 45 and 60 seconds.
6. Operating frequency: 5.0 megacycles per second.

The panels were laid up similarly to those in the oak study with the exception that the joint under test was made up of three 12-inch sections. The first 12-inch section had mix No. 1 applied to its edge joint, the second 12-inch section had mix No. 2 applied, and the third section was left dry and served as a filler piece in the panel. Immediately after the curing cycle was completed, the 12-inch sections were sawn into 2-inch blocks, broken open and examined for evidence of burning.

Fig. 6 A and 6 B indicate the minimum r.f. voltage gradients required for a satisfactorily cured glue joint as well as the threshold gradients for r.f. burning under the conditions of this test. In addition, it was observed that (1) on the jointed or sawn surfaces, the burns were in almost every instance associated with a region of dense fibers terminating an annual ring, and (2) on the ridged and grooved surfaces the burns invariably occurred along the ridges and in most cases along the grooves. At times additional burns were noted in the terminal fiber regions. See Fig. 7 A, B and C.

Referring once again to Figure 2 it may be argued that the value of R_d, the dielectric resistance, is a function of both the surface discontinuity and glue conductivity. In line with the electrical theory, the effect of an increase in conductivity of the glue mix is to decrease R_{g_2} thus raising the voltage across the the corresponding values of R_{g_1} and high resistance portion of the series voltage divider. The effect of a ridge due to nicked jointer knives is quite straightforward, both in theory and practice. The influence of a region of dense terminal fibers or of a groove may require further explanation. The differential swelling of the denser fibers when wet by the glue may result in a ridge of raised grain along the glue line, an effect similar to that experienced in the finishing of wood surfaces with a water-based stain. The high resistance induced by a groove may be due to the entrapped air in the groove. It was noted during the tests that the tendency to burn was more pronounced when the glue was spread on the wood surface opposite the groove than when it was spread

(Continued on page 71)

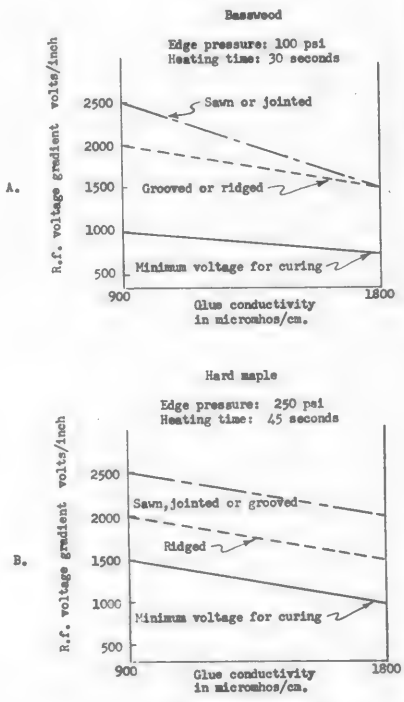


Figure 6.—The minimum radio frequency voltages for satisfactory curing and the threshold voltage gradients for radio frequency burning.

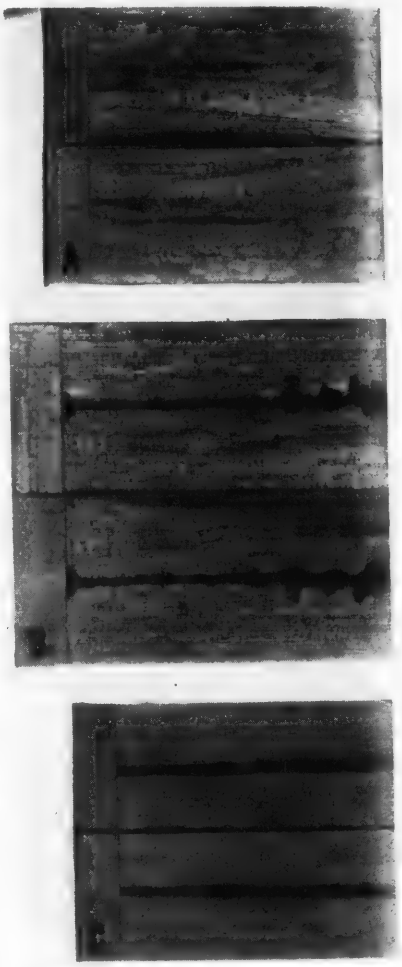


Figure 7.—A, radio frequency burning along lines of dense terminal fibers in hard maple—r. f. voltage gradient 2,500 volts/inch; edge pressure 250 psi., glue conductivity, 1,200 micromhos per centimeter; heating time, 45 seconds. B, radio frequency burning along a ridge in hard maple—glue conductivity, 1,200 micromhos per centimeter; r. f. voltage gradient, 2,000 volts/inch; edge pressure, 250 psi.; heating time, 45 seconds. C, radio frequency burning along a groove in basswood—glue conductivity, 1,200 micromhos/centimeter; r. f. voltage gradient, 200 volts/inch; edge pressure, 100 psi.; heating time, 30 seconds.

Rough Mill Efficiency

B. W. MASENGILL

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I HAVE OFTEN WONDERED about the different terminology used to name what I call the rough mill. In the Middle West, the rough mill is called just that. In the South and Southeast, the rough mill is called the "rough end". When we go farther north into Canada, the same department is called the "break-out department".

Primarily, the company with which I am connected is more concerned with the efficient flow of material through the rough mill than it is with basic machinery, but the two must be smoothly coordinated to assure an efficient rough mill. Since I am connected with a company engaged in the manufacture of rough mill conveyor equipment, I sincerely hope that no one will take offense if I lean slightly toward that equipment.

Importance of Prior Operations

In the past, and probably in the future, the rough mill department of any plant has started at the point where the lumber enters the cutting room and proceeds to the point where the lumber becomes dimension stock or glued-up panels. I would venture to say that more thought should be given to rough lumber from the time it is received at the lumber yard until it enters the plant. I am quite sure that the rough mill and all of the operations of the rough lumber ahead of the rough mill should be closely coordinated. I feel that it is very important to have the lumber properly stacked with ample sticks properly placed between the layers on the stack. To insure uniform thickness, in some cases it may be necessary to work directly with the sawmill operators. This has been done in several instances and has proven to be very worth while. Length and grade should be the determining factor in selecting the lumber from the yard.

I am quite sure that everyone here is well aware of all drying principles and problems. It is very important that the lumber be equalized after it is dried, and it is a common fault of manufacturers not to have the correct equalizing rooms or sheds. Let me say here that I believe that several companies would hire track men to repair their tracks and concrete their dry lumber sheds if they knew the amount of time consumed in repairs to tracks and transfer cars.

Importance of Grade

We believe that "rough mill efficiency" is largely determined by the grade of material used and its preparation before entering the factory. No manufacturing plant can operate efficiently unless is employs a material suitable for the product, and unless this material is put into the proper condition for processing. To make an illustration of this point—If you desire to cut stock 8 inches wide by 52 inches long, you of course do not want a rough board 7½ inches wide by 12 feet long. In this case, you would have approximately 1/3 waste in length alone. In other words, there must be available proper cuts to allow good material usage. I do not believe that I can overemphasize this point, as too many people think that any length and width of board can be obtained from any stack of lumber. You can readily understand that this is far from true because of the peculiar manner in which Mother Nature places knots here and there in the board.

We feel that a grade of material for any specific operation should be selected to give a yield of from 60 percent to 70 percent in finished products. In manufacturing core stock of the quality used in most wood products, relatively low grades of lumber will produce this yield. On the other hand, a much higher grade of lumber would be required to produce this yield in clear-faced solid panels. The reason for selecting materials that will produce within the above range is reasonably understandable. In operations yielding below 60 percent, too much of the workman's time would be absorbed in handling waste; while lumber for a yield greatly above 70 percent would in most cases be prohibitive in cost. All of the above may meet with variations in either direction, depending on the price of materials, freight rates, distance that materials must be transported, and various other factors.

Easy Handling Helps

When the lumber enters the plant, it is normally brought in onto a lumber lift, and I believe that some mechanical device or an electric eye should be installed on the lift to keep the lumber at the proper elevation for either the cut-off saw men or the planer operator. Also, these lifts should have ample horse power so that no difficulty will be encountered in bringing the lumber to the proper elevation quickly.

Rough mills should be so planned that a minimum of time will be required in the change-over from an emptied kiln truck to a loaded one. Numerous companies consume as much as fifteen minutes for this change-over. Returning the kiln trucks and necessary iron beams from the rough mill to the place where the bunks of lumber are built presents a problem in many plants. I know of one large factory, cutting almost 50,000 feet per day, where the kiln sticks, kiln trucks, and beams are returned to the two modern lifts where the kiln bunks are built by the same means used in Egypt 4,000 years ago —on the backs of the brawny colored boys who work on the yard. Considerable thought could be expended toward a monorail system to return these items to the lumber yard.

Cut-Off or Cut to Length?

Normally, the first operation in the rough mill is cutting to length or rough planing. A majority of manufacturers today are cutting to length first, but, of course, in some operations it is mandatory to plane first. Some plants today are practicing rough planing operations before cut-off operations because they consider that a minor cut on the board makes it possible for the cut-off saw operators to see better the defects in the lumber. We all know that there is a very controversial problem as to which is the better—cutting to length or planing first, but I believe everyone will agree that the primary goal for any woodworking plant is to secure flat panels. And we feel that by cutting to length and breaking the board where it is cupped before planing, a flatter and more level piece will be obtained.

The Five Essentials

We believe that there are five predominate factors in the operation of an efficient rough mill. These are: (1) Quality, (2) Conservation of materials, (3) Good basic machinery, (4) Material handling, (5) Trained personnel.

The most important of these is quality. There is no more thorough waste of time and man power than the manufacture of a product which can-

not be used because of its lack of desired quality.

Second, we feel that the conservation of material is likewise very important. In an average rough mill a workman may handle several hundred dollars worth of lumber each day. If one individual becomes careless, he can destroy enough material to pay the wages of every man in the rough mill for that day. In the plants where I have consulted with the chief engineers, the labor cost involved in preparation of material to the point of gluing is only 15 percent to 20 percent. According to these figures, it is readily seen that the labor cost up to the gluing operation is not the major cost of the product, thus allowing a plant to use more labor to increase yield.

Third, we feel that good basic machinery is very essential. The natural inherent abuse or rough usage which machinery of the rough mill must take requires that it be rugged. By reason of the production-line system where a break-down of one machine would cause work stoppage at a number of others, continuity of service of all machines is very important. Therefore, not only must the woodworking machines themselves be rugged, but each of the various types of conveyors connecting the machinery in a continuous production-line should also be like unto the "Deacon's One Hoss Shay"—as strong as all of the other component parts of the machine-conveyor combination.

If the material which comes to good basic machinery is not properly prepared, these machines cannot produce good work. On the other hand, if the material comes to good basic machinery in the proper condition and the machines are not in good mechanical adjustment, this will cause unnecessary waste and faulty material. Therefore, we feel that it is very important to have a good maintenance crew to check all conveyor belts, check all machinery periodically, and check all straight-line rip saws every eighty hours of operation to keep ahead of trouble. It is much better to take fifteen minutes to replace a bad bearing which you might find in a conveyor or machine than it is to waste several hours with a complete rough mill of fourteen or fifteen men standing idle. Another thing which should be checked regularly is the belt lacings on conveyor belts. I have been in several plants when the complete rough mill was shut down due to the fact that a mechanic was replacing a belt lacing.

We highly recommend the use of straight-line cut-off Saws rather than swing cut-off Saws, because swing saws will tire the operator much more than straight-line cut-off Saws will. We also believe that, in the industry as a whole, the stops on the cut-off saw gage bars are not being accurately set. An incorrect setting on cut-off saw stops will add up to quite a number of board feet daily. We feel that it is a very good idea to have a graduated scale to the left or the right of the cut-off saw operator to show him what length piece is left. The pointers should be set up exactly as the stops on the opposite side. This little feature will save much time for the operator. Carbide-tipped saws should be used on cut-off saws, as they will usually run for approximately six months without being sharpened. And, of course, the scrap from the cut-off Saws should be conveyed to a hog or a scrap box, so that it will not be necessary to handle this scrap.

When I think of material handling, I think of conveyors. Too many people in the industry have a false impression that to conveyorize a rough mill is to answer their prayers. However, in order for any rough mill system to function properly, there must be a smooth coordination between conveyors, basic machinery, and operators.

We highly recommend conveyorizing from cut-off saws to a facing planer, provided the material is cut to length before planing. In most cases it is necessary to face the material, and the facing planer is set in the line for the primary purpose of leveling the board. From there it should be conveyed to a single-head planer and reduced to a uniform thickness. If the facing and planing operations yield adequate flat surfaces, this will greatly aid in obtaining right angle joints in the edge jointer or in the rip-saw operations. We recommend after the planing operation an edge jointer, if the lumber does not have a large percentage of bark or wane edges. We find that, by the use of the edge jointer in the line, it costs only 65 percent as much to get a glue joint as it does to get one on the rip saw. From this saving the initial cost of an edge jointer and the automatic feeder and return feeder can be amortized in a short period of time.

If a company is manufacturing core stock, we recommend that the material be conveyed alongside a battery of rip saws. The rip-saw operator's job is to remove defects from any board which is convenient, regardless of length, and re-edge the boards not cleaned up by the edge jointer. On the other hand, if the company is primarily cutting dimension material, we recommend that specified lengths be conveyed to individual rip saws. I think that a lot of study could be applied to the use of a rip-saw gage. This gage has been put on the saw for a definite purpose—to keep the edges parallel, making for more efficient gluing operations—and we feel that it should be used. We recommend that all rippings from rip saws be returned to a scrap-saw operator for salvaging short cuttings. In one rough mill installation in North Carolina, we installed a scrap saw which saves $150 per day in lumber that heretofore was going to the boiler room.

We feel that all material in the rough mill, after it is cut to length, should be sorted onto factory trucks or onto some means of transportation other than pallets. The use of pallets is fine wherever a company can utilize a mechanized fork truck and retain an operator for the operation of the truck alone. In all other instances, we feel that it is most important to use factory trucks or some other means of transportation which will keep each stack ready for movement at any time. Ready movement in some cases can be obtained by use of roller or skate wheel type conveyors.

In addition to these standard conveyor items which I have mentioned, there are other conveyor items and attachments which do not necessarily fit into a conveyorized line, but which can be used to great advantage. For instance, the moulder-stock return is a unit which will amortize itself over a short period of time if it can be fully utilized. According to the best figures we have available on this unit, one operator on a moulder with a hopper feed and stock return can handle approximately 90 percent of the production of two operators on the moulder alone.

We have installed power-driven booster rollers which are an integral part of the conveyor to bridge the space between the end of the conveyor and the feed works of the facers and planers. There are several instances where booster rollers have cut out one operator.

In conveyorized core lines we have installed cross conveyors to return the lumber to the rip-saw belt and cut out the tailboy on the rip saw. This set-up is being used in plants where the lumber is of short lengths. If a plant has enough production for one cut-off saw, it is highly possible and practical to install a cross conveyor at the end of the planer and convey the board into the infeeder of the edge jointer.

Another feature which we have added to the infeeder and return feeder to the edge jointer is the power driven hold-down rollers which hold the lumber to the infeed bed before it enters the feed works of the edge jointer. *(Continued on page 68)*

The Steam Bending of Beech[1]

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THE OLD ART OF BENDING wood, following a softening or plasticizing treatment in steam or hot water, remains today the most economical and efficient means of producing wood members of curved form. Steam bending is widely practiced in boat building and in the manufacture of such products as furniture, chairs, handles, and sporting goods.

Beech is one of the relatively few woods that have been found particularly well adapted to bending. Because of its tendency to check on drying, the methods of treatment commonly employed with a number of other species, both before and after the actual bending operation, must be modified if best results are to be obtained with beech.

It is the purpose of this paper to clarify some of the problems encountered in bending and to promote a better understanding of the potentialities of beech in bentwood products. In gathering the information upon which this paper is based, the available literature on bending has been consulted freely. The author also drew upon observation of factory operations and the practical experience of manufacturers of furniture, athletic equipment, and other products made of beech.

Principles of Steam-Bending

Normal unheated wood can be bent to an appreciable curvature only in thin stock. A weakening effect is introduced when such wood is bent to a radius less than approximately 320 times its thickness and, if it is bent freely without support, fracture occurs at a radius of 50 to 80 times the thickness. Wood bent to a lesser degree, even though not ruptured, remains stressed in tension toward the convex face and in compression toward the concave surface. When unheated wood is bent, its elasticity tends to restore it to its original shape upon release from the external bending forces (12).[2]

When wood is subjected to moist steam or to boiling water, its compressibility is greatly increased—as much as to 30 to 40 percent—although its ability to elongate under tension—about 1 or 2 percent—is not much affected (8). It thus becomes possible to bend steamed wood to relatively sharp curvature only if the required difference in length between the convex and concave surfaces can be achieved by holding the convex face relatively constant in length and restricting deformation almost entirely to a shortening under compression (6, 12, 15).

Moderate curvature (to a radius as short as 25 to 30 times the thickness of the stock) can be accomplished without restraining straps and end pressure. However, if a curve of shorter radius is desired, it is customary to employ a metal restraining strap on the convex surface, attaching it to the wood in such a way that only a limited amount of elongation can occur during the bending operation. Under such conditions it is possible to eliminate tension fractures and, with species that tolerate a great deal of compressive strain without developing localized centers of compression failure, to obtain bends having ratios of radius of curvature to thickness as low as 1½:1. A further characteristic of steamed wood is that upon cooling and drying the bend "sets" and may be retained for many practical purposes upon release of restraint.

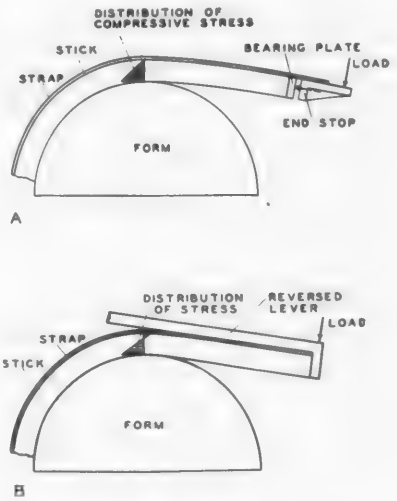
The principle of the restraining tension strap is illustrated in Figure 1, A. Here the end stops attached to the metal strap prevent elongation and thus limit all bending stress to compression, which is at a maximum at the concave face. The application of pressure on the convex surface of the piece during bending to prevent reverse bending and end crushing through avoidance of excessive end pressure is illustrated by the reversed lever in Figure 1, B.

Preparation of Wood for Bending

So far as the bending operation alone is concerned, successful bends can be made over a wide range in moisture content; but most satisfactory results are probably obtained at moisture contents near the fiber-saturation point, or approximately 25 to 30 percent. Green wood may contain so much moisture that hydrostatic pressure developed in bending may cause wrinkles to occur at the concave face of the bend (6). On the other hand, wood that has been dried to a low moisture content is too stiff to bend well without excessive steaming. A further consideration involves the problem of drying the stock, after it has been bent, to a moisture content consistent with its ultimate use. Consequently, it is usually advisable to season wood before steaming to a moisture content in the neighborhood of 25 percent and, in some cases, to as low as 12 percent.

Whenever possible, stock to be bent should be machined to approximate final shape and size so that, if necessary at all, operations following the setting and drying of the bend may be limited to sanding. Of course, this is not always possible, and machining operations that are sometimes awkward on bent stock may then be necessary. Surfacing prior to bending serves the additional function of removing saw marks and other irregularities that may induce compression failures on bending.

Both heat and moisture are essential to satisfactory softening or plasticizing of wood in preparation for bending. Treatment with steam or hot water is the best practical means devised for this purpose, although various chemical aids have been tried (4, 6). Experimental steaming has been tried at pressures higher than atmospheric, but there appears to be no advantage to



Fgure 1.—These diagrams illustrate the prinicple of the tension strap used in bending wood. In A end pressure is applied with a simple end stop. In B end pressure is regulated by means of a reversed lever. The differences in stress distribution are not inherent in the type of end stop. If absolutely no elongation occurs at the convex face the stress is distributed as shown in A. If limited elongation is permitted through partial release of end restraint, a stress pattern as shown in B will result.

[1] Published with permission of the Northeastern Technical Committee on Beech Utilization. This paper is one of a planned series of 22 reports of varied authorship being issued by the Northeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, Upper Darby, Pennsylvania, in cooperation with the Technical Committee.

[2] Numbers in parentheses refer to literature cited.

such procedures and, in fact, the higher temperatures may be detrimental to the wood.

Exposure to saturated steam at atmospheric pressure in a closed retort or steam box is the method most commonly used to soften wood. The steam should be introduced through water standing in the bottom of the retort, or other means should be provided to assure its saturation.

The duration of the steaming period will vary with thickness and moisture content of the stock and with the severity of curvature involved, but as a general rule green stock should be steamed approximately one-half hour and dry stock about 1 hour per inch of thickness (6). The additional period required for dry stock results from the need not only for heating but also for the addition of moisture to the surface zones.

Treatment by immersion in boiling water is essentially equivalent to steaming for a comparable period and is employed to advantage when only a portion of a piece is to be bent, as in certain types of chair posts and tool handles.

Methods of Bending

Free Bending

Free bending, that is bending without the use of a restraining strap, is successful only when relatively slight curvature is involved—specifically when the difference in length of convex and concave surfaces measured by the ratio

$$\frac{\text{thickness of stock}}{\text{radius of curvature of convex surface}}$$

does not exceed 3 to 4 percent. Probably the simplest means of bending wood is to force a stick around pegs fixed to a backplate; or to clamp one end of the piece to a male form and bend the piece to the shape of the form, wedging it at the opposite end of the bend.

Such bends may also be made in a hot-press equipped with shaped platens and steam-heated to temperatures approximating 250° F., as is frequently done in the forming of chair backs. Where more severe curvature is involved, the stock may be pressed in a bending pan that provides for end pressure (16). Retention of shape is obtained by retaining the bend in the press until it is dry. Free bends are also employed in boat building when steamed members are cramped into position and held in shape by attachment to a rigid structure. Another method of bending that does not employ end restraint—the intrusion method—involves forcing a straight piece through a curved mold (9, 11).

None of these methods is adapted to bending to sharp curvature without a substantial percentage of failures.

Restraining Straps

In contrast to free-bending methods are those that involve end pressure applied through restraining straps (2). Numerous hand-bending and machine-bending devices employ this principle, many of them also incorporating the reversed lever. The more complicated bends are usually made by hand by skilled workmen. Hand-bending methods may also be advantageous when only a limited number of bent pieces of a specific shape are desired.

Simple bends about a form can be made by hand, employing a mild or spring steel strap at the convex face of the bend and attaching the strap by means of end stops (6, 10). A brass strap is frequently used where discoloration of the wood from a steel strap is to be avoided. The strap should be at least as wide as the stick, and slightly-tapered wedges or end screws can be used to draw it tight.

The piece is usually clamped to the form at the middle of the bend and the two halves are bent to the form by hand (Fig. 2, A). A skilled operator

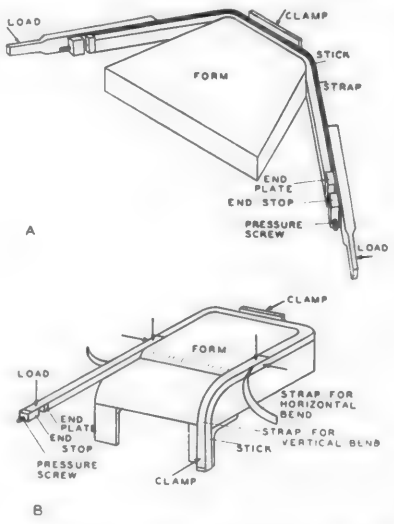


Figure 2.—Methods of hand bending wood. A, forming a simple bend by using a tension strap fitted with adjustable end stops. B, forming a bend that includes curvature in two planes.

applies pressure as needed to the convex side of the bend to avoid reverse bending in the uncompleted portion of the bend. Upon completion of the bend, the curved piece is held to shape by attaching a wood stay lath across its ends. Then it is removed from the form. The operation is accomplished within a few minutes after removal from the steam box.

Should the bend be so severe that fractures would occur at the convex face upon release of end pressure, the strap may be retained on the bend. The bend and strap may then be removed as a unit from the form. A bend of complicated shape may have to be retained on the form until set.

Straps with adjustable end stops to permit control of end pressure throughout the bending operation are especially suitable when long pieces of small cross section are being bent (10). Controlled release of end pressure helps to overcome the tendency for reverse bends arising from longitudinal pressure. Such release should not exceed 1 to 2 percent of the bent length (12, 17). Clamps may be used to prevent lateral bending at intermediate points.

When bends involve successive curvature in two planes (Fig. 2, B), a strap arrangement is required that will restrain elongation at the convex surface of any curved portion of the member. The first part of such a bend is made in normal fashion, clamped in place, and the clamped-on end stops are removed. In the bend shown in Figure 2, B, two additional straps attached in a plane at right angles to the main strap are next fitted to the remaining length and attached to the stick by means of end stops. The final portion of the bend is then completed in a plane at right angles to the initial bend. The finished bend is usually retained on the form for setting. Stock of round cross-sectional shape can be bent through use of a single flexible strap which is twisted about the piece, always covering the convex face (10).

S-bends may be made by using two forms placed in correct position and attaching to each a strap fitted with an

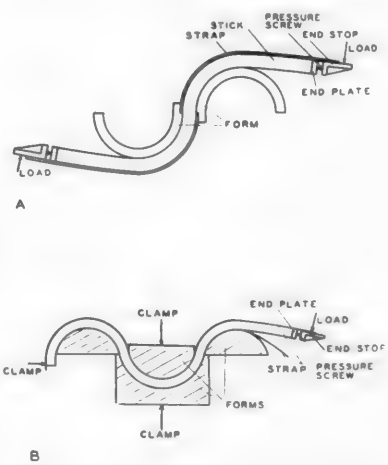


Figure 3.—Methods of bending S-type and re-entrant-type curves. A, an S-type bend employing a tension strap attached to each form. B, a re-entrant-type bend formed through the use of two full-length tension straps with the central part of the stick clamped in place after completion of that part of the bend.

end stop as shown in Figure 3, A. Two full-length straps, one on each face of the piece, may also be used successively (Fig. 3, B). As a portion of the bend is completed, it is held in place by forms and the end stops are removed; then the remainder of the piece is bent in the opposite direction.

Bending Machines

Bending machines are usually of either the lever-arm or revolving-form type (6, 9). In the lever-arm type machine (Fig. 4, A) the steamed piece *a* is fitted with a slightly over-length minor strap *b* on the face that will be convex in the bent member and placed against a fixed form *c*. A major strap *d* attached to movable arms *e* is fitted with end stops which are adjusted to the exact length of the piece to be bent. After clamping the stick to the form at the mid-point of curvature, the bend is produced through action of the movable arms, which are powered to force the piece against the form. These arms are arranged so as to bear progressively on the wood near the point that is being brought into contact with the form. If necessary, a slight elongation of the piece during the bending operation can be permitted through controlled release of end pressure by screw adjustment of the end blocks attached to the major strap. After completion of the bend, a tie rod is placed across the ends of the minor strap and; upon retraction of the lever arms, the bend and its minor strap are removed for setting. Several bends can often be made simultaneously through the use of wide straps.

With such equipment bends are limited to a maximum angle of approximately 180° in one direction. This type of machine is also generally limited to forming bends of continuous curvature such as chair backs or rockers.

Members that involve both straight and curved sections are usually produced more satisfactorily on machines of the revolving-form type. A revolving-form machine (Fig. 4, B) consists of a suitably shaped form *a* mounted on a revolving bed (9). A tension strap with end stops *b* is attached to the wood *c* and one end of the wood is clamped to the form. The bend is produced by the rotation of the bed; this automatically wraps the piece about the form. Pressure applied by means of a hydraulic piston *d* or spring-loaded roller is advantageous in bringing the bend into close contact with the form. Regulated release of end pressure during the bending operation is possible through screw adjustment of the end stop. This type of machine is adapted to all types of bends that can be made by lever-arm

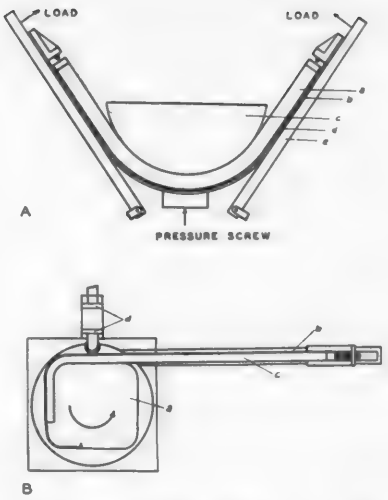


Figure 4.—Bending machines. A, a lever-arm machine showing the bent piece (a), minor strap (b), fixed form (c), major strap (d), and movable arms (e). B, a revolving-form machine showing form (a), tension strap with end stops (b), bent piece (c), and piston (d).

devices and, in addition, bends greater than 180° can be produced readily. For a bend of continuous uniform curvature the piece and its strap may be removed from the form when held to shape with a tie rod. When the member consists of straight and curved sections, it is clamped on the form, and the form, bend, and strap are removed from the machine as a unit. Among the bends made on this type of machine are table boxings and ring seats for chairs.

Setting of the Bend

A bent piece will partially straighten when released from restraint while still hot and moist. An insufficiently set bend of sharp curvature (relative to its thickness) is also apt to fail in tension upon removal of the restraining strap while still held to the curved shape. To overcome these faults, steam-bent pieces are usually set by holding them, together with tension straps and tie rods, in a heated room until they are dry.

Setting does not require drying, but merely cooling, if its objective is simply to hold approximately to a curved shape without rupture. However, bent members are subject to changes in shape with moisture-content variations and should be held to shape until dried to the approximate moisture content encountered most frequently in subsequent service. In the case of mild bends the tendency to spring back is not completely overcome even after drying, and such bends are often intentionally bent somewhat excessively to compensate for this anticipated spring-back (6).

Bent members are sometimes dried under ordinary atmospheric conditions without restraining straps as in the case of boat-framing members, which are customarily dried in place on the vessel. In furniture and chair factories, bent members in straps (and sometimes on forms) are often permitted to dry slowly under shop conditions.

If straps are removed before drying, bends ordinarily should not be set at temperatures above 100° F. (10). When straps are kept in place, however, bends are often dried in humidity-controlled chambers maintained at 140° to 190° F. and, with some species, at temperatures as high as 250° F. —in which case no control of humidity is possible. The protection provided by straps and end stops is undoubtedly helpful in avoiding checks and splits under these conditions. Bends made in hot presses are retained in the press until dry, usually at temperatures of 250° to 260° F. Regardless of the method of drying, the bend should be held to its desired shape until reduced to a moisture content suitable for ultimate service.

Bending Characteristics of Beech

In spite of the rather extensive use of beech in commercial bending over a long period and its generally favorable reputation as a bending wood, relatively little specific information is available in the literature to supplement commercial experience. European beech has enjoyed an especially favorable reputation for its excellent bending characteristics, although preferences have been noted for material grown in certain geographic areas, specifically the British Isles and the Carpathian Mountains of eastern Europe.

The Forest Products Research Laboratory in England has rated a large number of woods on the basis of experimental bending of carefully selected defect-free specimens, both with and without restraint (3). Using as a criterion the minimum radius to which 1-inch pieces could be bent without exceeding 5 percent breakage, European beech grown in the British Isles was successfully bent to a 1½ inch radius when tension straps were employed.

On this basis European beech was rated as a "very good" bending wood, equivalent to rock elm, black locust, Japanese oak, and sycamore maple, and surpassed only by white oak (1-inch radius) and Dutch elm (½-inch radius). Other "very good" species (which, however, were not quite so good as British-grown European beech) included American elm, Wych elm, European ash, and American ash. According to Peck (6), the following American woods of good bending

quality may be rated in descending order: American elm, white oak, black locust, beech, yellow birch, and red oak.

Without end pressure, 1-inch sticks of European beech (British-grown) were successfully bent to a 13-inch radius, comparable to American ash, white oak, and European oak. European beech (British-grown) was exceeded only by Dutch elm, black locust, European ash, Japanese oak, and Wych elm, and was followed by such woods as American elm, rock elm, European beech (imported), sycamore maple, and European basswood.

American Beech

The U. S. Forest Products Laboratory (6) has rated the following better bending woods in order of descending quality on the basis of percentage of breakage in a uniform bending test without end pressure: hackberry, white oak, red oak, chestnut oak, magnolia, pecan, black walnut, hickory, beech, American elm, willow, birch, ash, sweetgum, soft maple, yellow-poplar, and hard maple.

From these comparisons it may be concluded that beech is among the most satisfactory of bending woods, particularly when end restraint is employed. It also appears that American beech, while it may be somewhat less adaptable to bending than the best European beech, is not appreciably different from the average of European beech that has been so widely used in bent-wood products. This is substantiated by the practical commercial experience of furniture manufacturers.

One American manufacturer reports the successful bending of Adirondack-grown beech to a 3- to 4-inch radius, using ¾-inch stock and tension straps. Another states that breakage was prohibitive in hand-bending (with strap pressure) 4/4-inch beech to a radius smaller than 12 inches. But according to the same manufacturer, much better results were obtained when bending operations were performed on machines—because of the more uniform control of end and side pressure. Comparative tests led this manufacturer to the conclusion that slow-grown beech is superior in bending quality to faster-grown wood. However, specific data are not available to substantiate this conclusion. Manufacturers rather generally prefer sap beech to heartwood.

Bending Tests at Yale

In a limited series of bending tests conducted at Yale University (1), two methods of evaluating bending quality were employed. One of these was based on a visual estimate of quality. One-inch defect-free stock at 20 to 30 percent moisture content was steamed and bent to an 8-inch radius using a restraining strap (removed upon completion of the bend) and holding the unrestrained specimen to shape with a stay lath attached across its ends. A rating of "excellent" was used for pieces in which compression failures were inconspicuous; those with evident compression failures extending less than half the depth of the specimen were designated as "good"; those with prominent compression failures extending from mid-depth up to ⅛ inch from the convex face were rated "fair"; others which showed either tension failures or compression failures extending throughout their entire depth were rated "poor".

From two shipments of beech originating in Cooperstown, N. Y., and Harrisburg, Pa., 24 specimens were bent to an 8-inch radius. Of these, 9 rated "excellent", 10 "good", and 5 "fair". A few white oak specimens bent under comparable conditions were rated "excellent". When bent to a 6-inch radius, most of the beech specimens were rated "fair", and those bent to a 10-inch radius were rated "excellent".

The second method of evaluation of bending quality was based upon results of a strength test after the bend had been set and dried. In a static-bending test, patterned after a method used at the U. S. Forest Products Laboratory (5), maximum fiber stress sustained by the bent stick when loaded on the convex face as a beam was compared with the modulus of rupture of straight unsteamed specimens of matched material. Any reduction from modulus of rupture values for straight beams is indicative of the damaging effect of the bending process.

The average loss in strength of all 1-inch beech stock which had been bent to an 8-inch radius was 32.1 percent. (The comparative figure for white oak was 26.1 percent.) "Excellent" beech bends of 8-inch radius showed an average loss of 27.8 percent; "good" bends lost 31.7 percent, and "fair" bends lost 38.6 percent. In bends to a 6-inch radius, strength loss averaged 36.2 percent, while at a 10-inch radius the average strength loss was only 14.8 percent. In these tests no significant influence of specific gravity or of sapwood vs. heartwood was found, although admittedly the data are too limited to be conclusive.

The foregoing results support other evidence that beech is a very satisfactory bending wood and only slightly surpassed in this respect by white oak. Oak is, of course, well recognized and widely used for its excellent steam-bending qualities. White ash, elm, and hickory are similarly employed. Because of its finer and more uniform texture, however, beech is not apt to be used interchangeably with these species wherever appearance is a factor. The evaluation of beech as a bending wood is therefore of greatest practical value when it is compared with such woods as yellow birch and hard maple, and on this basis beech is readily recognized as possessing superior bending qualities.

Entirely independent of bending quality but, nevertheless, factors which cannot be overlooked in the evaluation of beech as a bending wood are the problems of seasoning lumber prior to bending and of drying the set bend. In fact, the satisfactory solution of the checking problem may well be regarded as the key to successful bending of beech.

Recommended Practice in Bending and Drying Beech

Because of the inherent tendency of beech to check upon drying, particular care is required in the handling of logs and lumber prior to steaming or boiling.[3] Losses as high as 50 percent in bending beech, attributable largely to checking, have been reported in commercial operations where methods adapted to the processing of birch and maple were used without modification. The checking of beech sticks during the drying period after bending poses another serious problem.

In principle, the most practical solution appears to be to control drying carefully during the preparatory period to bring the stock virtually check-free to the lowest moisture content compatible with the degree of curvature desired. For bends of a radius equivalent to 6 to 8 inches or less for 1-inch stock, this probably will involve drying only to 20 to 25 percent moisture content. Where atmospheric conditions do not permit air seasoning of beech to such moisture contents without harmful checking, resort should be made either to chemical seasoning or to drying under the temperature- and humidity-controlled conditions of a kiln. For less severe bends, seasoning to moisture contents as low as 12 to 15 percent, preferably under controlled mild drying conditions in a dry kiln, is suggested in order to minimize later difficulties during the subsequent drying of the bend. It is, of course, entirely possible to steam and bend green stock fresh from the log if facilities for slow, controlled drying of the bent stock are available.

So far as selection of material suitable for bending is concerned, beech is no different from any other wood. For severe bends stock should be straight-

[3] The problems of storing and seasoning beech to minimize checking are discussed in other papers in the beech series.

grained (a slope of grain steeper than 1 in 15 is considered excessive) and free of all knots, localized grain irregularities, decay, or comparable defects (6). It has been clearly demonstrated that even pin knots, which would be insignificant for most uses, may introduce serious buckling at the compression face in steam-bent members (7). At the other extreme, short moderate bends for such items as chair backs are commonly made from ordinary factory cuttings of No. 2 Common grade lumber.

The steaming or boiling periods specified for wood in general are applicable to beech; i.e., ½ hour per inch of thickness for green wood and 1 hour per inch for wood that has been dried to 12 to 15 percent moisture content. All of the bending methods described in this paper are applicable to beech.

As with other woods, bends of beech that are dried following removal of straps should be dried slowly at temperatures below 100° F. When straps are retained on tension surfaces, however, and end stops protect the end surfaces of the stock, beech may be dried successfully in heated chambers at temperatures up to 150° or 160° F., particularly if relative humidity is controlled to regulate rate of drying. Green beech bends 1 inch thick have been successfully dried in 16 hours, and air-dry stock in 12 hours under such conditions (10). Thicker stock may require several days of drying. Under certain conditions somewhat lower temperatures may be necessary to avoid checking and splitting.

Properties of Bent Wood

Steam-bent wood that has been fixed and dried changes in curvature with subsequent variations in moisture content. As a result of changes in thickness and shrinking or swelling of the upset wood toward the concave face of the piece, the bend tends to straighten at high humidities and to increase in curvature at low humidities. However, the changes induced by swelling are not completely reversible, and after a cycle of wetting and drying the bend fails to recover its original shape. Consequently a bent piece of wood retains its curvature only when maintained at a constant moisture content or when held in shape by attachment to other members of a rigid structure. Hence the need for holding the bend by means of straps and tie rods or on forms until dried to approximately the moisture content that the wood will have in its ultimate use.

After fixing and drying, the strength of bent wood is lower than that of normal wood at the same moisture content. For the better bending woods, at least, such loss of strength is attributable to the over-stressing that occurred in bending and not to the plasticizing effect of the steaming treatment, which is only temporary. At a radius 140 times the thickness of the bent stick, practically no strength loss in either static- or impact-bending occurs in the case of good bending wood, even when loaded so that the concave (upset) face is stressed in tension (17). As bends increase in severity, however, the strength loss becomes appreciable. Losses in static-bending strength (concave face stressed tension) for 1-inch beech were previously referred to. When bent to a 10-inch radius, strength loss averaged 14.8 percent; at 8 inches loss was 32.1 percent; and at 6 inches 36.2 percent. These losses are due primarily to weakening at the concave face and are greatly reduced if only the portion of the bend toward the convex face is considered.

Figure 6.—Comb-back windsor chair with back and arm bow of beech.

Similar tests reported by Wilson (17) on portions of a bent wheel rim showed that whereas the full section developed a modulus of rupture of 8,000 pounds per square inch, smaller sections representing the inner and outer halves of the bend developed values of 7,300 and 12,400 pounds per square inch respectively. It is evident that the efficiency (strength-weight ratio) of a bent stick is greatly improved if the wood toward the concave surface is subsequently removed by machining.

Beech Bent-Wood Products

The principal use of beech in bent form is in furniture, particularly in chairs. Colonial windsor chairs of the patterns shown in Figure 5 are frequently made of beech, maple, or birch. In these chairs the top bows and rockers are steam-bent. The comb-back windsor chair pictured in Figure 6 has a back and arm bow of bent beech. The posts of Hitchcock and ladder-back chairs are often made of steam-bent beech, although many manufacturers have turned to birch or maple because of their greater tolerance for rapid drying.

These graceful colonial designs that made such effective use of steam-bent members were augmented in the latter part of the 19th century by light bent-wood chairs that had their origin in Austria. Possibly such designs reflected the feeling that much of the massive furniture of the period was greatly oversize and very wasteful of a dwindling timber resource. At any rate

Figure 5.—Colonial windsor chairs for which beech is frequently used in top bow and rockers.

Figure 7.—New York bent-wood chairs in which steam-bent beech is commonly used in seat framing, backs, and bracing.

there is little question but that the Austrian type of bent-wood chair represents an extremely efficient use of wood through the almost exclusive employment of steam bends in bows, legs, bracing, and seat frames. An American modification of this type, known as New York bent-wood, is shown in Figure 7, which pictures chairs of a type widely used in schools and cafeterias. Steam-bent beech is employed in such chairs in the form of seat framing, backs, and wish-bone braces. A circular seat frame of beech is shown on its bending form in figure 8, A and an unfinished arm bow for a windsor chair in figure 8, B.

Bent beech has its use in modern living-room furniture too. Beech was used extensively in many of the modern bent-wood designs of the 1930s (Fig. 9, left) in both chairs and tables. If properly handled to avoid checking, beech is well adapted for use in modern living-room items of current manufacture (Fig. 9, right) for which sap birch is now in much demand.

Other uses for steam-bent beech include such sporting-goods items as tennis racket and squash racket frames and hockey sticks. A laminated tennis racket frame employing steam-bent beech is shown in Figure 10.

The bending qualities of beech are well adapted for these purposes and are supplemented by its many desirable strength properties—including resilience, hardness, and abrasion resistance. In many types of curved handles for tools and implements, steam-bent beech is either used at present or its potential use may be anticipated where maple or birch are currently employed satisfactorily. Beech lacks the degree of shock resistance that is usually required in bends that are subjected to severe impact loading and for which rock elm or hickory are commonly employed. The use of beech in bent members in boat building appears to offer some possibility of replacing scarce bending oak, provided suitable means of seasoning and drying of bends to avoid excessive checking can be assured. Where, as in boat hulls, a decay hazard is associated with the conditions of use, beech requires preservative treatment.

An interesting scheme for the employment of beech in bending, as yet undeveloped in commercial practice, has recently been proposed in England (13, 14). By the prior gluing of a thin layer (1/16-inch) of European beech to what later becomes the compression face of a bend, a combination 1-inch thick of beech and an otherwise desirable wood lacking good bending qualities can be steam-bent to a radius as small as one-third of that possible for the poor bending wood alone. The potentialities of this technique may be of particular interest in connection with furniture items in which only the wood of attractive figure on the convex face of the bend is exposed.

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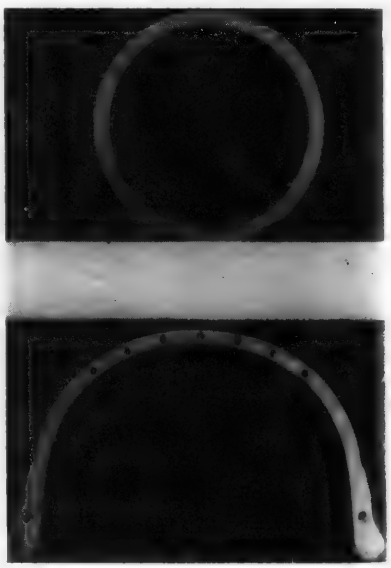

Figure 8.—Chair parts made of steam-bent beech. A, a circular seat frame on its bending form. B, an unfinished arm bow for the type of chair shown in Figure 6.

Figure 9.—Uses of bent wood in modern chair design. Left, design popular in the 1930s. Right, a modern upholstered chair, for the bent-wood arms of which beech is well adapted.

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Figure 10.—Steam-bent tennis racket frame, made up from laminations of beech and white ash.

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Use and Maintenance of Carbide Wood Cutting Tools[1]

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INTRODUCTION OF ALMOST ALL NEW MATERIALS, processes or products has been accompanied by confusion and trouble. In the use of carbide as a metal for cutting wood, the many problems involved have been accepted as a challenge by those who refuse to believe "it can be done".

Before going into specific details of some of the obstacles that have confronted the fabricators and the users of these tools, let's take a brief look at some of the fundamental principles by which any product—new or old—is evaluated.

Economics

There can be little doubt that the primary principle upon which tungsten carbide wood cutting tools should be evaluated is economic. Stated in its simplest form, it is this—"Unless tungsten carbide tools will produce more superior work pieces at a lower cost per work unit than is possible with any other cutting tool made of any other material, then they should not be used on that particular operation." This particular challenge is being met by improved methods of application and operation. Production reports are continually proving that more and more production problems can be and are being solved efficiently and economically by carbide wood cutting tools.

There are many instances where these carbide tools have proved their economic worth. One of the most amusing and interesting involved a manufacturer of school furniture who had kept a very accurate record of the production cost of a carbide saw in operation, from January 11th to May 19th on a straight-line rip saw. When these figures were compared with those of standard steel saw operating costs, the purchasing agent decided to purchase a new carbide saw and scrap the dull one. He had not understood that this saw could be sharpened and again go into production. This incident ties in very closely with actual records which show that it requires an average of less than 9 man hours per *year* to maintain carbide saws on a saw arbor. Nine man hours would certainly not go very far toward maintaining carbon steel saws on the same arbor. The time study department of a West Coast plywood flush door manufacturer determined that the use of two carbide saws, operating 750 hours on a double-end trim saw, would save them $151.60 in sharpening costs on each saw previously used. That saving would have replaced these saws; yet they were resharpened for $10.00 each. These figures did not take into consideration the saving in down time or production loss.

For example use of carbide knives on oak flooring has shown that by using approximately $2100 worth of carbide knives and cutters, the tool cost per lineal foot would run approximately 2 mills on the first run. Sharpening of all cutters could be done for under $50.00. On the basis of one and a quarter million lineal feet of production, this maintenance cost would be a small fraction of one mill per lineal foot of flooring on subsequent runs.

The initial price or investment in carbide is often greatly overemphasized. The initial price should be considered in terms of production costs of the finished product. This program requires close comparison to present productive costs with carbon or high-speed steel blades. It is advantageous to remember this important distinction between initial tool price and their true cost as determined by production records.

With this brief discussion of economic value let's discuss carbide wood cutting tool application, operation and maintenance.

Application

The application of carbide wood cutting tools to any type of wood machining operation should, of course, pass the economic test just discussed. If they will not produce faster, better and cheaper, they should not be used. You may ask, "How can this fact be determined if we have never used carbide wood cutting tools?" With the past experiences of others and the guidance of a competent carbide tool representative, it is possible to make a thorough study of your production problem, your equipment and usual operating practices. Very often the ability or inability, to machine some particular material is the determining factor. Many of the newer laminates, plastics, or other compositions cannot be cut for even a brief period with high speed steel tools. In other situations, dimensional accuracy or quality of finish will influence the decision to use or not to use these carbide tools. It is quite possible that all these factors can and should be considered as a part of unit production costs. Regardless of how these factors are evaluated or in what order of importance you may place them, they all must be considered as economic problems. Therefore, the economic factor rates high in considering applications.

There are other important factors which must be considered. The machines upon which you propose to run carbide wood cutting tools must be checked very carefully. Arbors must run true with little or no vibration. Feed chains, belts, tables or tracks must be set and maintained accurately. Guides, fences, hold-downs, pressure bars, chip breakers, or other adjustments must be set and locked accurately in position. Worn parts should be replaced to eliminate or reduce chatter to the lowest possible degree. This will usually require some careful inspection and work on your present machines, but it will really pay dividends in increased production, lower unit costs and improved quality of finish. The problem of the economic value of equipping part of a multiple head machine, such as a molder, is frequently discussed. Several firms have adopted this solution. On molders where one or two surfaces are consistently flat, straight carbide knives can be used on those heads which produce the flat surfaces. The volume of molding with one or two contour surfaces of any particular pattern may be small and could be run without stopping to hone or grind the carbon or high speed steel knives. This reduces the set-up time, as the straight carbide knives will continue to machine the flat surfaces throughout many changes of contour or profile knives or heads. Where the same pattern is run over and over, with a lapse of time between runs, a solid type carbide cutter or head with ground or milled-to-pattern carbide knives can be kept ready to put on. These cutters or heads would require only occasional sharpening between runs.

Carbide circular saws and groovers are more widely used than any other carbide wood cutting tool. While pieces which go into a finished product may not be shaped or molded, few if any get through without passing over one or more saws. More is known about carbide saw applications than other carbide tools because of their wider use. Yet there are many more places

[1] Presented at meeting of the Forest Products Research Society, Ohio Valley Section, Louisville, Kentucky, October 2, 1952.

where these valuable productive tools could be used to advantage. Some have had unfortunate and costly experiences with these carbide saws. *More* have used them successfully. A competent carbide service man can often determine the cause or causes of your troubles.

Operation

Your operating conditions may or may not determine whether carbide wood cutting tools will prove a practical and economical solution to your production problems.

Your present operating conditions are no doubt geared to the requirements of your product or to the desires and needs of your customers. These conditions are also often adjusted to meet competition.

The condition of the material you machine and the accuracy or grade of finish required will control to a considerable extent your operating procedures. Furthermore, the higher the grade of the product you are producing, the more exacting will be the requirements for craftsmen and mechanics. These better trained and more experienced men, as a rule, adapt themselves more readily to the use of carbide tools. When the installation of carbide tools is being considered, a close survey of all production operations should be made by your own personnel or by a trained production man from outside. In a number of plants, such surveys have disclosed various processes which, if corrected, would bring additional savings.

Centralized control of all carbide wood cutting tools should be the responsibility of a competent individual, or department, depending upon the size of the plant. Regulation of operating conditions, transfer, storage and maintenance of carbide tools should be delegated to this individual or department. This method will prevent abuse of tools in mounting, operation, transfer and maintenance. Such responsibility, when delegated to a conscientious person, will usually result in improved service from all carbide tools.

Since carbide tools must be carefully handled to and from the machines and in storage, it is advisable to provide suitable cases or holders for transporting these tools to and from the machines. These cases can also be used as storage cases.

Operating conditions will include the arbor speeds and work feeds at which the tools are to be operated. Arbor speeds on woodworking machines are almost all determined by the speed of the motor. Most are direct motor driven with 3,450 rpm standard except where frequency changers have been added. Some recently designed machines have provided a wider variation in arbor speeds with quick-change V-belt pulleys. The most efficient operating speed for carbide knives is yet to be determined by tests now being run.

The tendency to run the feed mechanisms of many woodworking machines at top speeds is neither efficient nor economical unless selective feeding can keep a continuous flow of material into the machine. To run the machine feed faster than material can be fed to it will not in itself increase production. Unless material feed of all other production machines can be increased in proportion, the increased production of one machine will be lost.

Work feeds will vary with the materials to be machined. Carbide tools will machine most woods at higher rates of feed than is possible with high speed bits or cutters, and will produce comparable or improved finish surfaces.

Maintenance

Maintenance of carbide tools is such an important part of an efficient and economical operation that it requires individual consideration. Without accurate maintenance, maximum production is not possible. Whether this resharpening is done in your own plant, sent to a commercial repair station or is included in your rental contract for carbide tools, it must be done carefully and accurately. Due consideration of the work to be done will determine the cutting angles, clearances and bevels required. Final finish grind requires the use of diamond wheels.

A most important contribution to carbide tool maintenance education or training is the course to be offered at the University of Michigan and North Carolina State College this fall and winter. These initial courses are a cooperative undertaking by these schools and industrial firms who supply parts, tools or equipment to the woodworking industry. A number of men who are experts in various phases of this industry will aid in presenting the technical lectures and supervise the actual grinding practices. Manufacturers of grinding machines and carbide tools will supply the best and latest type equipment for class use. Two of the leading grinding wheel manufacturers have assigned their best field men to explain and demonstrate the latest grinding technics in care of carbide and high speed steel tools.

Jointing of carbide knives has been discussed more often and vigorously than any other item connected with the use of these tools. While jointing of formed carbide knives is still some distance from a satisfactory solution, straight knives can, with the proper set-up, be jointed. This jointing must be extremely light, followed by careful honing to a sharp edge. Announcements of equipment and instructions will be made shortly. This jointing, of course, refers to knives used on molders or matchers. The care required to properly maintain these tools emphasizes the need for centralized control of these productive tools to insure accurate resharpening, on an established schedule to obtain the longest possible tool life.

To summarize, there is sufficient evidence to prove that carbide wood working tools are both efficient and economical when they are: (1) Applied carefully on stable machines in good to excellent condition, (2) Used where production, finish, or accuracy requirements justify their application, (3) Operated according to acceptable requirements of good production practices, (4) Given first-class care both on and off the machines and (5) Maintained accurately on an established schedule.

When these conditions are met, the vast majority of well managed woodworking plants can enjoy the efficient and economical use of carbide wood cutting tools.

Stellite For the Woodworking Industry[1]

B. C. MacKENZIE

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THE MACHINING OF WOOD with Stellite has been a subject for special study for some time and although the applications of the alloy to many different types of cutters can now be recommended, the field is so vast that there is still much experimental work to be done. However, sufficient has been achieved to make broad recommendations.

A tremendous advance in the use of special alloys for tools for the metal working industry took place during the last war when the greatest production in the fastest time was essential. From the successes in this field, the woodworking industry quickly followed, to obtain similar advantages during the closing years of the war when it was realized that a faster output of wood products with better finishes and many more units per sharpening could be attained. The use of thse alloys has multiplied tremendously in recent years. Competition and the growing cost of labor now make it imperative that both tools and machines be operated with the maximum possible efficiency with a minimum of shut down time.

What Are the Stellite Alloys

Included in these special alloys is one group classified as the Stellite alloys. In the metal working field these alloys are known as the cast alloys. They are not steels because they contain only a negligible amount of iron. They have an approximate analysis of 65 percent cobalt, 25 percent chromium and 10 percent tungsten. The proportions of their constituents together with their carbon content are varied over many different grades to suit specific requirements of toughness, hardness, and sometimes corrosion resistance.

There are many factors that influence the usefulness of a metal for cutting operations. Generally speaking, as the alloy content of any tool increases so increases its wear resistance. Possibly the easiest way to illustrate the importance of the alloy content in tooling is to compare the service obtained from ordinary carbon steel knives as opposed to those made from high speed steel. High speed steel contains about 25 percent alloy of tungsten, chromium and/or vanadium with 75 percent iron. Carbon steel contains no alloy. Most companies have used knives of both types. In spite of having the same hardness, high speed steel invariably yields more pieces per sharpening than carbon steel knives.

Thus, it can be seen that hardness has little bearing when comparing the wear resistance of different materials although hardness does serve as a useful indication when comparing similar materials. For example a carbon steel knife of 58 Rockwell hardness cannot be expected to cut as long as a carbon steel knife of 62 Rockwell hardness. However, in certain circumstances high speed steel of 58 Rockwell will cut longer than carbon steel of 62 Rockwell. The Stellite alloys being all alloy with negligible iron will provide even longer service than steels which may contain only from 10 percent to 30 percent alloy.

This improved service is partly explained by the fact that Stellite loses none of its hardness up to 1550° Fahrenheit and will drop only a point or two in Rockwell hardness up to 1850° Fahrenheit. Thus it is apparent that as the temper of Stellite cannot be drawn or the metal softened by heat, it will not wear as rapidly as steel during cutting. Every mechanical operation develops heat by friction and even when operating at normal temperatures high surface temperatures are developed on the face of the wearing part. Even though this high surface temperature cannot be measured with ordinary instruments, iron-base alloys soften and wear on a thin surface from frictional heat. The inherent hardness of Stellite even at elevated temperatures enables it to resist wear to the greatest extent both when red hot and at room temperatures. Because of this property which we call red hardness (a poor name because steels do not necessarily have to be red hot to wear) Stellite does not have to be as hard as steels to outwear them. There are literally hundreds of examples where Stellite of only 50 Rockwell hardness outwears high speed steel of 65 Rockwell from 5 to 10 times even when operating at room temperatures: paper slitters, locomotive throttle cams and woodworking tools are good examples.

One other property of this group of alloys which has some bearing on the long service obtained on woodworking tools is its resistance to corrosion, again because of the negligible iron content. Certain wood acids will attack steels to form oxides on the surface of a cutting or working edge. Oxides of iron are referred to as rust. Such oxides on the working edge of a tool, even though hardly visible and only molecular in thickness are constantly being abraded away when the tool is in use to exaggerate the wear on a cutting edge.

The effect of this corrosive action is best illustrated with the use of pressure bars on veneer slicers. Within just a few minutes of operation of steel bars on certain woods, stain caused by acid attack will often appear on the pressure bar side of the sliced veneer. This stain is actually part of the metals on the working edge of the bar being eaten away by the wood acids and being carried away by the veneer. On the same job this stain has been completely eliminated even after weeks of operations without a grind with the cobalt-chromium-tungsten alloy pressure bars. It is easy to visualize what can happen on the thin edge of a steel woodworking knife or blade. While only minute, it is nevertheless playing a definite part in removing the tool's cutting edge.

The Stellite alloys, however, are not without their limitations. Tools working under friction are subject to three physical strains: (1) Pressure due to the load on the working edge. (2) Abrasion, which varies with different materials being worked. (3) Heat developed by both these physical actions.

No one metal is a cure-all to combat all of these conditions, since some tools obviously require greater strength or shock resistance while others function longer by making the most of their red-hardness properties. Successful tools made from Stellite are limited to certain designs because Stellite, being a cast material, does not have as much strength as a rolled or forged steel. The type of woodworking tool best suited for Stellite must therefore be of a design to provide ample support for the Stellite edge.

Where Stellite Tools Are Used Effectively

Mention was made that sufficient has now been achieved to make broad recommendations concerning the use for Stellite. There is little doubt that variations in feeds, speeds and cutting angles are going to improve the life and output from these tools still further. Such information covers mechanical modifications which will be

[1] Presented at meeting of the Forest Products Research Society, Ohio Valley Section, October 2, 1952, at Louisville, Kentucky.

collected and published as time goes on and as the use of these alloys become more widespread. This much is known:

1. The only successful Stellite woodworking tools produced up to the moment have been those containing a 30° included angle or more.
2. If a steel tool is failing due to chipping or nicking of the cutting edge then Stellite, not having as much strength as steel, cannot be expected to stand up on the same operation.
3. Experience now tells us that on hardwoods Stellite invariably provides big life increases per grind as compared with high speed steel or carbon steels, whereas, on soft woods the slight comparative life improvement does not justify the higher cost of Stellite with one exception which has been uncovered so far and which will be described later.

The first two are best illustrated by referring again to veneer lathes and slicers. Stellite pressure bars which last as much as 25 times as long as steel bars have from 70° to 80° included angle and thus plenty of support for the Stellite. As a result, they stand up to as much abuse from foreign material in the logs as steel bars and in fact they will often shear through nails more effectively than steel. (The use of Stellite shear blades having an angle similar to that on pressure bars has been standard practice with the steel mills for many years for cropping steel). However, the veneer knives which have only 20° to 30° included angle generally must be sharpened more often because of nicking even with steel knives rather than from wear, so that the use of present grades of Stellite for the knives is not yet a recommended proposition.

The one exception that has been uncovered so far for the successful application of Stellite on softwoods has been rotary shaper cutters. To cite an example, a paint brush company now cutting the radii of paint brush handles with Stellite cutters formerly had to stone up their high speed steel tips seven times a day and usually open up the radius of the cutter to a new size every day. When they changed to Stellite they were able to hand stone the flat of the Stellite tips while it was still in the machine about four times a day until the entire thickness of the Stellite tool had been stoned away. This cutter lasted about seven or eight months before being discarded, and the original radius was held for this entire period. This was on poplar and basswood paint brush handles.

The Stellite alloys have proven very effective on imported woods containing a high silica content or abrasive resins. For example one firm formerly had to sharpen their steel cutters after cutting about 1/3 the length of African walnut. The Stellite on the same production cut about 25 complete lengths for about 75 to 1 life.

Another producer of fishing rods is now using Stellite faced angle cutters for split cane sections. With high speed steel they were getting about 50 units per grind. After changing to Stellite the cutters now give 700 per grind and even when the wear is slight they require only a minimum of reconditioning.

Mention may also be made of two other aspects concerning the application of Stellite which are of interest to the woodworking industry. These are mechanical rather than metallurgical. Tools made from Stellite do not require special expensive grinding wheels to sharpen them as many have thought. They are ground with exactly the same grinding wheels used for steel tools although sharpening does take a little longer. They can be ground dry and will not burn even if they become red hot but should never be quenched from elevated temperatures. If water is used when grinding, a *flood* of water is desirable and imperative to eliminate intermittent heating and cooling.

2. A perfectly homogeneous surface of Stellite can be produced in any lengths even on 17-foot pressure bars. Some have queried at times as to whether small pieces are brazed into place on a working edge later to leave marks on the wood being processed where the pieces were joined. This is not a factor with Stellite because the metal is welded into place for any length leaving no joins or gaps.

Conclusion

All these developments have been made possible with the metallurgical advancements during and since the last war and the creation of modified grades of Stellite made especially to suit specific problems in the woodworking industry. None of them would have been possible without the fine co-operation extended by the woodworking industry. It has taken some time and experimentation to work out some of these but in the course of progress woodworking methods have been greatly improved through the use of suitable grades of Stellite which provide:

—The toughness and wear resistance so necessary for applications like pressure bars or hog anvils.

—The ability to last from 5 to 10 times longer than steel for working hardwoods or for laminated woods where there is a severe glue line abrasion.

—The ability to last up to 25 times longer than steel against the silica and resin abrasion of imported woods.

—The ability to maintain contours on multitooth shaper cutters as much as 200 times longer than steel working on soft woods.

One special grade of Stellite has even been put into service which will develop a slightly ragged (but not too ragged) edge in service. This is used on long wearing shaper knives in order to leave a roughened surface on toilet seats to afford a better bond for hard rubber coating.

There are still a few unknowns which time and experience are solving. These, at the moment, cause about one Stellite tool in five to fail even though it is working on the same operation but in a different plant. Yet the Stellite has come from the same production. The variations seem to be in the wood being worked and possibly operating conditions so that changes in the tool angles, speeds or feeds are indicated. These operational changes can and are being worked out more satisfactorily by the woodworking companies themselves who are more familier with the mechanics of wood cutting than the manufacturer of the alloy whose specialty is metallurgy.

Progress has been, therefore, a co-operative effort and continues because of the many values already described. Any expense involved with the one tool in five that does not live up to expectations is of course more than amply covered by the substantial savings obtained from the remaining four —a condition which is recognized and allowed for by those woodworking manufacturers who are constantly improving their production through the increasing use of Stellite for their woodworking operations.

Review of the Productivity Team Report on Furniture[1]

THE PRODUCTIVITY TEAM consisted of 16 representatives of the British furniture industry. It spent 6 weeks in America and visited 22 furniture factories plus a number of furniture exhibitions, machinery makers, etc. The reports on individual visits have been rearranged according to subject so that for example all references to seasoning appear in one section. The Report includes detailed recommendations based on a comparison of the American and British industries.

General Survey

The differences between the furniture industries of the U. S. A. and the U. K., which must be taken into account when considering the details contained in the Report are emphasized. Among these are the more plentiful supply of the traditional timbers in the U. S., the use of core-stock made by the furniture manufacturers themselves instead of block-board or plywood and as a result the greater size of the rough mills required for preparing the timber, the use of polishes finished by rubbing instead of pulling-over, and the more frequent changes in design necessitated by the half-yearly furniture exhibitions. Other essential points are the greater emphasis placed on production engineering, the break-down of manufacture into separate specialized operations with less reliance on craft training and apprenticeship and consequently the greater mobility between the furniture and other industries.

Factories

A brief comparison is made between the factories visited and typical factories in this country. The more important differences are the use of multi-story buildings and the general installation of sprinkler systems (B115).

Materials Handling

That handling adds nothing to the value of a product but only to its cost is more generally recognized in America. Great attention has therefore been given to the installation of all types of materials handling equipment which in many cases does not require power operation. The report gives details of a large number of handling methods in the various stages of furniture manufacture. Timber on arrival is immediately stacked on kiln trucks where it remains for several months air-drying before entering the kilns. After kilning the timber is unloaded in the rough mill with the aid of a lumber lift which rises slowly so that the top boards on the truck are always at a convenient working height (B214). In the rough mill and the machine shop, the machines are so placed and connected with conveyors that the timber passes through a series of operations with the minimum of handling, sawdust, chips and off-cuts being removed automatically (B215–6). Some of the examples described involve extensive conveyor systems but, as far as possible, advantage is taken of gravity or simple sliding methods. An example of a simple practice is the use of a short rope weighted at both ends hung over stacks of long pieces on trucks to prevent the side pieces falling off. Overhead suspended conveyors are frequently used in finishing departments but these have two disadvantages, namely that the work tends to swing during the spraying and rubbing operations and the spacing and speed of travel must be uniform throughout the length of the conveyor. A better type consists of rectangular pallets moved along a light framework by a driving chain. When required, e.g., during the drying processes, the pallets are turned sideways to occupy a minimum amount of space (C52, 64).

The team emphasizes that improved materials handling is one means by which unproductive labour can be avoided and the standard of living raised.

Cabinet Goods Production Technique Materials

Much American furniture is made from plain, solid timber. Where veneered wood is used it generally consists of core stock veneered with the timber used in the solid parts. Cabriole and shaped legs of reproduction furniture are usually built from several thicknesses of 1 inch timber glued together to form a block. A thick veneer with its grain at right angles is inserted between each lamination to prevent warping.

Various adhesives are used. One firm using only synthetic resin stores its glue in a central reservoir from which it is pumped to work stations. Hardware is specially made by the hardware industry for the individual manufacturer. In view of the shortage of rattan, use is being made of round-section steam-bent ash treated to resemble the traditional material. Tubular steel furniture is generally made for special purposes but competes with rattan for outdoor use. Occasional tables frequently have hide tops elaborately tooled with gilding.

Seasoning and Kilning

Great care is taken in seasoning timber and this is done by combining air and artificial drying. Loading and unloading the kiln trucks are facilitated by the use of mechanical devices and a simple and rapid method of correctly placing the laths for stacking the timber is described in detail. There are no great differences in kiln drying. One unusual kiln design is described in detail.

Drying schedules are severe compared with those in Britain, temperatures being as high as 200° F. Drying times are short and the risk of casting boards is accepted. Drying is simplified by the practice of cutting all timber to a thickness of 1 to 1½ inches, and by the use of a limited number of species.

In America it is usual to dry the timber to 5 per cent moisture content then leave it in stabilizing sheds for up to 7 days.

Rough Milling

The rough mill forms a relatively large part of an American factory. A description is given of a typical layout which includes automatic feeding and off-bearing for cross-cut saws, and conveyor feeding for either edge-jointers or straight-line edgers as required. In most cases joints can be glued straight from the saw and at the latest are not left for more than one day before gluing. Three devices for accelerating cross-cutting are described.

Construction of Core Stock

As alternatives to revolving cramps, batch-type panel jointers may be used in which the core stock is pressed between platens heated by steam or high frequency methods. Continuous panel jointers are also used in which the core stock travels through a steam-heated press and is cut into panels as it emerges. Individual pieces in cores may be up to 5 inches wide without causing difficulty, presumably because of the climatic and living conditions in America.

Veneering

Decoration by the use of veneers is not popular, face veneers being plain and unmatched except for mahogany veneers used in reproduction designs. Veneers are jointed by guillotine, flying saw or continuous feed jointers.

[1] Reproduced by permission from Supplement to Technical Bulletin 8, published by The Furniture Development Council, 11 Adelphi Terrace London, WC2, England, March/April 1952.

The splicing is usually done on tapeless veneer splicers sometimes with longer tables and higher speeds than are common in England. To reveal any bad joints in the veneers coming off the tapeless splicer, a glass panel illuminated from below can be let into the table on the output side. Several methods are described for removing the glue liable to accumulate on the hot sole plates of these machines.

Most veneered parts are made from core stock, the usual practice being to apply the cross banding and the face veneers to the core at the same time. For easier handling the panel may be assembled on an aluminum caul. Another caul is placed on top and the "sandwich" is moved in and out of the press, the cauls being the same size as the hot platens. The advantages obtained are quicker loading and less risk of precuring.

Although multi-daylight presses are usual, several large factories use single daylight presses of a quick-acting type and with a short pressing cycle. Automatic or hand-operated loading devices are used for multi-daylight presses. The cauls are stacked for cooling in a specially designed truck which supports them on edge. The equipment used is simple and could be constructed by most maintenance departments.

A number of ingenious machines designed for edge veneering were seen. A machine commonly used consists of two thin iron strips heated by low-voltage electricity. These are pressed against the veneered edges of the panel by compressed air rams or a piece of rubber-lined canvas hose inflated by compressed air. Another method is used to cross-veneer simultaneously three sides and two rounded corners of thick desk tops.

In one factory, mahogany curl veneers are treated with a proprietary compound, flattened and backed with a thin soft whitewood cross-veneer before laying to prevent cracking.

Timber and Plywood Bending: Curved Plywood

A machine described for bending flat plywood enables small radius bends to be made without first reducing the thickness at the bend as is usual in this country. Curves in one plane only are made by one firm by placing glued veneers between a pair of metal dies of the appropriate shape (B206–7). Though the dies are expensive, they are considered economical for long runs. Compound curvatures are obtained by using an inflated bag between two dies, the veneers being set by electrically-heated blankets. For complicated shapes pressure is applied progressively from one portion of the curve to another by using two or more bags which are inflated in turn. The products vary from cupped chair seats to complex shapes considered impossible by most manufacturers. It seems that new designs are first planned and the manufacturing technique then developed accordingly.

Machining

Double-end tenoners are widely used for trimming and forming simultaneously both ends of a component. They are frequently equipped with cam actions on both top and side heads so that stopped grooves and shaped ends can be cut (B185). Four-cutters are similar to those used here.

Many machines are arranged so that one feeds material to the next, e.g., a finger feed surfacer can be coupled to a thicknesser. Examples are given of arrangements by which one operator can carry out a sequence of operations on a component using several machines, these arrangements having been suggested by the operators.

Instead of our type of dovetailing machine the majority of plants use two machines, one cutting the pins on two drawer sides simultaneously, the other cutting the mortises or sockets on fronts and backs. Other machines cut dovetails on both ends of drawer fronts simultaneously and bore holes for handles where necessary.

Methods of constructing and assembling drawers are described including a method of fitting drawer bottoms which leaves no gap between the bottom and back. Multiple borers and mortisers are commonly arranged so that tables or drills rise and fall automatically and continuously, the worker removing and inserting a piece between each stroke. Speeds of over 20 strokes a minute are normal. A reference is made to the multiple drilling of dowel holes.

In larger plants two types of automatic shaper are used, the Onsrud machine with a revolving table (B7) or the Whitney power feed spindle moulder. Hand carvings are made with the aid of revolving cutters held against the wood by hand, a high degree of skill being developed and a very high rate of production achieved with little physical effort.

A very interesting section of the Report describes devices for obtaining quicker or better results. Many of these are illustrated.

Sanding

Great attention is given to mechanical sanding and special machines have been devised for this purpose.

An attachment to the out-feed end of the drum sander for detecting surface imperfections is described. Various types of belt sander are used, including the mechanical stroke sander. Opinion is divided as to the merits of this machine.

Fifteen special devices for sanding assemblies and complete carcasses are described and illustrated.

Assembly

Methods engineering is widely used to avoid the accumulation or haphazard distribution of machined pieces. The components reach the assembly stage in accurate quantities. Carcasses are assembled on assembly lines but power-driven conveyors are not always necessary. The methods engineering staff decide the processes and provide the jigs and devices for speeding work and production control. The aid is to shorten the time taken by the worker and reduce physical effort to a minimum. Some methods used to achieve this aid are described.

Sub-Assembly

Details of the construction and gluing of drawers are given. Hide glue is almost universally used and as soon as the drawers are cramped they are passed to the sanders. Triangular glue blocks are used instead of drawer slips. Various devices for glue application are described. Automatic gluing and dowelling machines are occasionally used. Alternatively, both ends of rails stacked on trucks can be glued and dowelled by hand in large batches. High-speed assembly is ensured by careful planning, meticulous machining and the use of sound materials.

Chair Making

No factory visited specialized entirely in the manufacture of chairs.

The manufacturer relies on methods engineering to devise machinery and assembly techniques for work normally done by hand here.

Seat joints are of dowelled construction. Special purpose high-production machines are described for making chair components. The thickness of timber seldom exceeds 1 inch, two or more thicknesses being jointed up and resawn when thicker material is needed.

The manufacture of upholstered seats for dining chairs is described in detail.

Polishing and Finishing

Lacquer finishes thick-sprayed and rubbed down to a level surface are commonly used in America. (See Tech. Bull. No. 7, p. 31). No factory was using the hot lacquer system as known in Britain. No attempt is made to recover any of the materials from the water-wash booth and some manu-

facturers consider that a water-wash booth is an unnecessary luxury.

Apart from tradition, the marked difference of method in the two countries is due to two factors, namely that the hard lacquer finish with severe cutting down is not suited to the plywoods generally used in Britain, and the lacquer itself is more costly and less readily available here. At one plant, lacquer was applied by coating rollers operated similarly to the doctor roll glue spreader, the edges being sprayed while stacked. Force drying combined with the use of conveyors effects a great saving in floor space, eliminates intermediate handling, and saves time.

Fitting-Up and Despatch

The fitting shop is included in the production planning scheme and automatic hand tools and conveyors are used to secure greater output. There is a marked difference between packing methods in America and Britain. Non-returnable container cartons bearing the firm's name are produced for almost every piece of furniture. A soft cotton-like paper wrapping is in general use and the cartons are reinforced with wooden slats or metal angles. The furniture is priced ex-works and may be transported very long distances at the purchaser's expense.

Upholstery Production Technique

Loose hair and fibre fillings are seldom used. Materials are usually 54 inches wide.

Hand-sprung seats are usually stapled to the webs, and top-lashed. Types of prefabricated spring units popular for lower-priced furniture include zigzag spring bases used with pocketed spring units, and various combinations of steel laths and tension springs. Frequent use is made of a 1 inch thick foam rubber pad placed over a ½ inch rubberized hair pad on top of the springing. Good-quality back springing is carried out by hand. Pocketed spring units and zigzag springs are also used for backs but specially moulded foam rubber is found to be too expensive. A good result is obtained with pocketed spring units in which the outer springs are stronger than those used in the centre of the back. Arms are seldom sprung. Methods of filling cushions automatically are similar to those used in this country. Cushion covers are sometimes closed with zip fasteners.

Coverings for low- and medium-priced furniture are cut in batches using cloth-laying machines and vertical knives. These knives are attached to overhead rails which supply the electric current thus eliminating trailing cables (D32). Paper spools are used in sewing machines to eliminate re-winding. A special cushion closing machine is available for sewing covers after filling.

A practice recommended by the team is the labelling of upholstered furniture to indicate the nature of the filling. This labelling is compulsory in certain States.

As in other work construction and assembly are broken down into numerous small, easy operations. Each operator soon becomes expert in his job, and time and effort are saved. A typical method of producing an easy chair is described in detail.

Special devices observed include a steel webbing into which springs can be simply laced in position (D46), a stapler for fixing springs to webbing, a mesh for use on top of springing to prevent fillings from sinking between the springs (D50), a hand tool for cutting foam rubber up to 4 inches thick (D109) and a hammer-type stapler (D85). The magnetic hammer is widely used. Fringes and ruche have their edges chain stitched to prevent tangling. When they have been sewn in position the chain stitching is pulled out to allow them to fall normally.

Safety

The American practice is to rely on the development of "safety-consciousness" among all concerned rather than on safety regulations and thorough guarding. Safety campaigns in the factories have kept accident rates down to a level comparable with our own and it is suggested that a blending of the American and British methods might lead to still lower rates in both countries.

Radio-Frequency Heating

The use of R.F. equipment is not general because the rapid glue setting valuable with plywood construction is unnecessary with the solid timber and core stock used in America. The only use of R.F. equipment for assembly work was in the manufacture of television cabinets.

R.F. heating is, however, used for building up solid tops and ends using batch or continuous type jointers. These machines are described.

Use of R.F. was noticed in a portable machine called the "wood-welder", which is used for setting small amounts of glue in repair work. Whilst the apparatus is useful in skilled hands, it appears to be rather flimsy and possibly dangerous for general use.

Management

A feature of American industry in general is that "management" is often distinct from "ownership". This leads to greater mobility amongst managers who may move freely from one company to another. A considerable proportion of management staff, particularly in methods engineering, is found by promotion in the factory after a trial period.

Production engineering plays an important part in the industry. Executives with specialized training in methods engineering are engaged from outside, given a grounding in furniture manufacturing and then employed with others who have been promoted from the shop floor. This staff is responsible for very detailed planning of production including the routing of components and day-to-day production control. Details are given of various systems used.

Similar attention is given to planning office methods, cost accounting and the preparation of estimates. Emphasis is placed on the value of accounts, prepared at frequent intervals, as a means of revealing present conditions and forecasting the future. Tabulated examples of costs and trading results supplied by four furniture firms are given.

Industrial Relations

A description of the organization of the Trade Unions is given and it is explained that entry into the industry is open to anyone. The more obvious disadvantages of this system are counteracted by the operation of a "Seniority List" within each firm. This maintains the interests of the employees with the longest service who receive privileges when transfers between departments, promotion, short time or redundancy are being considered.

Wages are determined by a process of job evaluation. The factors which are taken into account include the knowledge, training and physical effort required and the working conditions and responsibility involved. Care is taken to explain to the employees the union contract applicable to each firm, including the procedure for dealing with grievances.

In most factories some incentive scheme is in operation, usually based on the timing of operations. This timing is generally carried out by staff recruited from the workers in the factory or trained in each department before commencing this work. The procedure used is fully explained to the employees and an opportunity given for grievances to be dealt with. The use of professional time-study engineers or consultants is uncommon.

Other aspects of labour relations dealt with include suggestion schemes and the use of publicity within the

(Continued on page 68)

Veneer Splicing[1]

W. JETER EASON

Secretary-Treasurer, Nickey Brothers, Inc., Memphis, Tennessee

TO A PERSON UNINITIATED in the various woodworking arts, one of the most fascinating discoveries is the rapidity with which veneers can be spliced edge to edge. Fragile veneers are shuttled to and fro through the splicer and back with apparent disregard for the delicate nature of the material.

A close inspection of the process reveals that the bond between the veneers is often stronger than the wood itself, and that the operators are in reality quite skilled in the manipulation of the sheets of venner and actually careful with the material.

Types of Splicers

At Nickey Brothers we employ two types of splicers: (1) the conventional or pass-back type and (2) the continuous cross feed. We have 10 conventional splicers, one of which is equipped with a high-frequency unit in addition to one resistance type heater bar, while the other nine are equipped with two Calrod electrical resistance heaters. The continuous machines are both equipped with high-frequency units. One of these machines is 50 inches wide, and the other is 100 inches wide; that is, will take stock 50 inches and 100 inches long continuously cross fed.

The conventional splicer equipped with the one additional electronic unit is at present used largely for making small lumber cores.

The conventional splicers are familiar to everyone concerned with the problem of veneer splicing. Strips of veneer with smooth longitudinal edges to which glue has been applied are fed in the direction of the grain, side by side into the machine which supplies horizontal and vertical pressure as well as heat. The strips emerge from the machine bonded together. In order to make a large sheet consisting of many splices, the previously spliced portion of the sheet must be returned to the infeed end of the machine to have another piece added to it, and so on until the required width is attained.

The continuous, electronically heated machine operates differently. While in the pass-back machine the veneers travel parallel to grain of the wood, in the continuous operation the veneers travel perpendicular to the grain. The veneers are laid on a continuously moving belt ahead of the machine. Although care should be exercised in alining successive sheets so that the ends are against a guide parallel to travel of the belt, the veneers do not need to be alined perfectly edge to edge manually on the belt. The feed belt travels faster than the feed in the machine itself and hence the veneers catch up and are alined in the machine. Horizontal and vertical pressure are applied and the glue is set up by the dielectric heat.

Application of Pressure

An important factor in splicing is horizontal pressure. In the conventional method this pressure is applied by means of traveling endless chains above and below the veneer whose lines of travel converge at the outfeed end of the machine. The surfaces of the chain links are knurled in order to grip the wood, but some lateral slippage must occur due to the taper mentioned above. The lateral slippage is determined by degree of vertical pressure. This is controlled by moving the entire assembly containing the upper chain up or down as required. Thus it is seen that the horizontal pressure interacts with the vertical pressure so that the two may not be set independently. Another adjustment controls the spring tension applied downward on the chain. This adjustment controls the horizontal pressure through the control of the slippage, and it also affects the vertical pressure to some degree. The vertical pressure need only be sufficient to hold the material flat. The heater bar which is located between the chains traveling over the veneer can be adjusted vertically with respect to the chains. This adjustment is part of the control over the vertical pressure required to hold the veneers flat. In order to eliminate to a considerable degree the human error in alining the veneers before entering the chains, this type machine is equipped with rollers at the infeed end. The rollers have a toe-in and a vertical pressure adjustment. Both of these adjustments affect the alinement under the chain and hence have a bearing on the vertical and horizontal pressure on the glue line. It is important to avoid excessive vertical pressure in order to avoid indenting the veneer.

In the case of the continuously fed, electronically heated machine the horizontal pressure is obtained differently. The belts traveling above and beneath the veneer travel at a slower rate at the outfeed end of the machine than at the infeed end, causing a build up of pressure through the machine. The veneer is held flat by pressure from the belts, which, in turn, are held down by bars acting against them. The bars are held against the belts by means of air hoses between the bars and a fixed surface. Thus the vertical pressure is controlled by the pressure in the hoses. The air is supplied to the hoses in three groups through the machine, so that different vertical pressures may be obtained at the infeed, center, and outfeed portions. The vertical and horizontal pressures are not entirely independent in this machine, as was also found to be the case with the conventional machine. Some slippage must take place and the vertical pressure regulates this from a crumpling effect at the high extreme to an overlapping effect at the low extreme.

In both machines the speed is regulated by a manually controlled variable drive.

Application of Temperature

The temperature is regulated in the conventional machine with a thermostat controlling the resistance heaters. In the same type but with the added electronic heating machine and in the continuous machines, the temperature regulation, of course, is more complicated. The temperature depends upon the power delivered to the glue line, which in turn depends upon properties of the wood and the mixed glue. These properties of course vary from one run to another depending upon species, thickness, etc. However, the properties of the wood and mixed glue may vary from time to time within a particular run unless considerable effort is expended in striving for uniformity. Of course the temperature in the glue line on the standard electrical resistance type machine cannot be assumed to be constant merely because the Calrod element is thermostatically controlled. Variation in the wood affects the transfer of heat in both machine types, but the variation in glue line temperature with properties of the material in the machine appears to be greater with the electronic equipment.

With veneer splicers, as well as with other wood gluing equipment, the method of applying heat by high frequency presents different problems

[1] Presented at meeting of the Forest Products Research Society, Ohio Valley Section, Louisville, Kentucky, October 2, 1952.

from the method of applying heat by conduction. In the first place the glue must be carefully studied, and the various adhesive manufacturers have developed glues which perform satisfactorily for particular operations. It should not take long to locate a satisfactory glue for any operation due to the manner in which the adhesive manufacturers are set up at present.

In the electronically heated machine the electrodes consist of two sets of bars located over the veneer and positioned parallel to the line of travel—and at right angles to the glue line. Every other bar is connected to a common terminal, there being two such terminals. Thus the heating is accomplished by the stray field method. The manufacturers of our particular machine claim their circuit is very satisfactory since a change in the load affects the circuit in such a way that the load and the circuit shift together with a tendency to maintain a resonant condition.

The conventional machine with added electronic heating employs a high frequency generator. This unit has been equipped with a device known as the "arc stopper" which tends to anticipate an arc and kicks out the machine when an arcing condition is present.

Both electronic generators operate at 26 megacycles. The conventional type with electronics added and the 50-inch continuous machine both operate at 2½ kilowatts while the large continuous machine operates at 5 kilowatts.

Without going into the finer points of gluing with electronic equipment, one obvious factor must be controlled in electronic equipment that is not of comparable importance in other heating methods. This concerns the dryness of the wood. The glue line must be wet as it enters the machine in order to be sufficiently selective over the dry wood to be heated by the dielectric field in the time required. In the conductive heating method, the glue may be allowed to dry out short of setting up and a good joint may be obtained when the heat melts the glue, permitting it to flow before setting up.

Excessive glue causes both types of splicers to become fouled with caked glue, and glue on the splicer line is often difficult and costly to remove. Excessive glue in an electronic unit is conducive to arcing and should be carefully avoided. The glue wheel applicator must be kept in good shape with the electronic unit in order to get a uniform spread, since a low spread is likely to dry out and a high spread is likely to allow the glue to cause arcing or burning.

Preparation of Stock

As with every other woodworking operation that comes to mind at the moment, the preparation of the stock is a very important step. For best results veneers should be of uniform length and width, which of course implies straight parallel edges. Veneer sheets should also be square, of uniform thickness and moisture content, and they should also be flat.

Buckled stock can sometimes be anticipated in the log, and such logs should not be run into veneer if possible. When face woods are found to be buckled when uncrated, they can be made flatter by pressing in a hot press, especially if the moisture content is not too low. This is a good argument for maintaining a fairly high moisture content—say 15 percent—for face veneers subject to buckling.

Rarely can buckled veneer be clipped so as to make a straight enough edge. A common occurrence is for the knife to draw the veneer toward it in clipping, making the piece narrower at the center than at the ends, where the sheet is held. A precision, paper-cutter-type clipper equipped with a massive hold-down may prevent this from happening. But this is no positive assurance that the edges will be straight. Pressing down on and cutting a curved surface will not necessarily make it flat. Also stresses in the wood sometimes make the veneer crook after clipping. A second clipping will not guarantee straight edges.

The conventional splicer, if sufficiently slowed down, can tolerate considerable buckling. However, while this is a plus for the splicer, the subsequent hot pressing operation may not tolerate the same degree of buckling and splits or overlaps may result. Buckled face veneer can sometimes be restored to a satisfactory condition by rejointing on a traveling-head jointer, using only a few sheets to the book.

Another useful technique with buckled stock is to splice the veneers in pairs and then joint the remaining exposed edges until the buckle is removed before running the spliced pairs through the splicers again.

Our experience with our large continuous electronic machine indicates that this machine is not as tolerant of buckled veneer as is the pass-back type in which case, with only one glue line at a time being fed through the machine, only the veneer in the vicinity of this one glue line is held flat. In the continuous machine, on the other hand, an entire spliced sheet must be held flat, making the sheet susceptible to splits or overlaps if the veneers are not flat and do not have straight parallel edges. Thus in this operation greater emphasis must be placed on flatness and straightness.

With thick veneers buckling is seldom a major problem. But with thick veneers the conventional machine has great difficulty in drawing up joints which are not straight and so for thick stock, and in this particular regard, there is not as much difference in performance between the two machines as there is with thin veneers. However, the method of feeding each machine creates its own separate problem. With any method of splicing, veneer with edges out of parallel are likely to make rainbow-shaped cores and controls over parallelism are necessary in order to avoid defective plywood. When veneers are not parallel, in the case of a continuous crossfeed machine, there is an additional disadvantage created in that a continuous sheet of rainbow-shaped material will not emerge straight from the machine and will cause obvious difficulties.

Veneer shaped like a parallelogram, with parallel edges but out-of-square corners, also causes trouble. In the conventional machine such pieces may cause a whole sheet to be shaped like a parallelogram with the disadvantage that the plies in the plywood will not be perpendicular to each other, and also with the possibility of the panel not fully sawing out. In the continuous machine out-of-square pieces will cause additional difficulties in that in attempting to place the ends of the veneers against the guide at the infeed end of the machine, the sheet is likely to be so placed that the belt grabs one corner of the sheet first with the result that the other end of the veneer swings into line later, making the out of square piece protrude from the rest of the pieces in the sheet. It is very difficult to feed out-of-square pieces correctly into the machine with the jointed edges perpendicular to the line of travel at the beginning of a run or following an interruption. If the first pieces are not fed in correctly also subsequent pieces will lie at an angle even though they are sized properly before being delivered to the splicer. This out-of-square situation is likely to accumulate so that the operator sometimes inserts an out-of-square piece in the opposite direction in order to reestablish the required degree of squareness. Squareness can also be maintained by turning out-of-square pieces over, or turning them end for end.

Moisture Content

Moisture content is a property of wood that affects just about everything that is done with the material, and perforce moisture content also affects splicing. With the conventional machines excessive moisture content

sometimes causes the metal parts of the machine to stain the veneer. This is objectionable and costly with face veneers, even though the stain subsequently may be removed. The continuous machine employs fiber belts so that this problem is eliminated. It is possible for moisture content to be so high that no bond is obtained with the conventional machine due to the fact that the heater bar in this, the electrical resistance type machine, heats and dries out wet veneer in contact with it, so that the veneer tends to curl around the bar. This ruins the veneer for face stock. Excessive moisture content with the continuous electronic machine will cause the tubes to draw more current and the machine will kick out. Thus this method serves as a good protection against delivering wet splice core stock to the glue spreader. Burning and arcing occasionally occur, but this can be largely eliminated with the help of professional advice and experience, and every precaution should be taken to avoid it.

Operation and Maintenance

In running sliced face woods we at Nickey Brothers practically always use book matching. With the pass-back method the operator keeps track of the matching by working with pairs of sheets. Several pairs of sheets are spliced and then the remaining spliced pairs are run into a whole sheet. With the continuous machine every other sheet must be turned over and it appears for this reason that greater attentiveness is required to avoid mismatching through carelessness.

There are many more adjustments on the conventional machine than on the other. Considerable skill and experience is required to set up properly the conventional splicer to compensate for the different woods to be run. With the continuous machine the adjustments are simpler but the stock must be more nearly perfect since the machine is not tolerant of imperfections.

The conventional machines require ordinary maintenance for wear and tear on the equipment and the Calrod units need replacing occasionally. Electrodes in the electronic version of this type need replacing more often than in the other types.

The continuous, electronically heated machines are quite new and we have not yet had enough experience to compare intelligently the comparative maintenance between the two types.

Waste Factors

Because of the continuous nature of operation of the new equipment, a saving is realized since there is no trim waste in sizing the veneer sheets. The waste factor with the older machines can be reduced by reclipping and rejointing the trim so that there is an advantage in splicing up sufficient material to make a trim strip wide enough to salvage. However, with matched face woods such trim strips often must go into mismatched panels.

With the continuous machines the elimination of the trim strip is particularly advantageous with face veneers that must be matched. As yet these machines have not been made to do completely satisfactory jobs consistently with face woods. This apparently is due not only to the material being thin, but also to the fact that perfectly straight joints are not easy to obtain with the thin veneers. In order to correct this trouble we are attempting to eliminate the jointing operation and are gluing clipped edges on our 100-inch machine. There are still some bugs in this relatively new operation; however, considerable progress is being made and a degree of perfection has been attained that indicates eventual success.

Production Rates

At Nickey Brothers we use large quantities of 1/6-inch Philippine mahogany for core stock. We are able to get about 28,000 sq. ft. of 4-by-8 sheets in an eight hour day through a pair of conventional splicers and about 30,000 sq. ft. a day through the 50-inch-wide electronic machine. We require three men for this operation and seven for the other operation which includes the clipping and handling operations. The small but necessary amount of reclipping required for the continuous system is done by the clipper serving the pair of conventional splicers. While this small extra cost should be charged to the continuous machine, the absence of it would not release anyone from the other operation. With the continuous machine the emerging sheet of spliced veneer trips a mechanism which automatically clips the veneer to size; thus this clipper cannot be used for reclipping and reclips are accumulated and reclipped at convenient intervals.

We manufacture quite a bit of plywood consisting of three plies of 1/11-inch Philippine mahogany. This construction calls for spliced faces and backs. We can get about 16,000 sq. ft. a day of spliced 1/11-inch 4 by 8 sheets through a pair of pass-back splicers with seven people. We can get about 30,000 ft. a day through our 100-inch continuous machine with three people.

Summary

We find that we can get more production with fewer men with less floor space through our new method than before, but in order to achieve this advantage extreme care is necessary in the preparation of veneers. However, if the continuous-cross-feed electronic machines are in the plant they will of necessity create a need for improved quality, and improvement in quality is bound to happen when the need is so strong. On the other hand older machines are more versatile and for this reason at least, there probably will always be veneers which are suitable only for these splicers. I hope that I have adequately presented some of the factors involved in splicing, and have explained the problems and results from the two basically different types of splicers which we are using.

Recent Developments in Masking Overlays[1]

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THE PRODUCTION of Douglas-fir plywood surfaced with overlays of various types continues to attract increasing attention from both plywood producing units and research organizations of companies interested in becoming suppliers of overlay materials. The reasons for this are not difficult to ascertain and have been well publicized in recent years. As plywood production figures continue to mount astronomically, the procurement of high grade fir peelers for face stock becomes more and more of a problem and ways are being sought to upgrade and extend existing supplies of wood veneer. As examples of this trend, it has been recently stated[2] that in about 10 years, most of the plywood plants in British Columbia will be forced to look for face materials other than fir; it has been estimated[3] that in southwestern Oregon at the 1947 rate of cut, the old growth timber would last about 50 years, but since plywood production is fast approaching a figure twice that of 1947, this estimated figure is shrinking in proportion.

As a result of these trends, increased utilization of second growth fir and less desirable species such as hemlock, white fir, and western larch, will be mandatory. For many applications it will be desirable to improve the surface of these with some sort of overlay, to arrive at a first grade panel with first grade performance characteristics. Also, the utilization of white pocket Douglas-fir ("pecky fir") is becoming a serious problem. In some areas of southern Oregon, 90 percent of the old growth is reported to show white pocket. There should be a good opportunity to exploit overlays in up-grading such veneers. It appears inevitable that overlays in several forms are to play a more significant part in the future of the plywood industry.

Development of the Overlay Idea

The growth of overlay production, while increasing steadily, has not been at the rate one might expect. This has probably been due in part to the extremely heavy demand for regular plywood in recent years, as boom times for a regular item tend to slow development of new products. Also, the education and selling of the ultimate consumer on the value of such new products is a slow and tedious process. Other factors which have limited production are the following.

1. Hot presses are required. This eliminates cold press mills and a substantial part of new production is cold press.
2. Present plastic surfaces require at least a solid or "B" grade veneer directly under the overlay, and "B" grade is difficult to obtain in quantity.
3. Difficulty in obtaining aluminum cauls. Cauls are necessary to obtain the best possible finish. The aluminum shortage is, of course, a transitory situation.

When the time does come that the fir plywood industry is sharply competitive again and is forced to look for improved surfacing raw material, then it is anticipated that more manufacturers will want to turn to overlays by way of developing specialties and new lines to hold and expand markets.

By way of review, it would perhaps be in order here to define and classify the various types of overlay surfaces available or under development. The term "overlay" itself is generic, as it includes a multitude of combinations involving wood, paper, metal, plastics, veneers, or composition materials. As papermakers, we are concerned primarily with paper-plastic combinations. Seidl[4] of the Forest Products Laboratory has conveniently classified paper plastic overlays according to function and properties as listed in Table 1.

To further delineate the types that will be discussed in this paper, we have arbitrarily subclassified the masking overlays into two types (Table 2). Their purpose and characteristics are the same as given in Table 1 under "masking."

Plastic-surfaced Douglas-fir with high density or structural type overlay have been made since the early days of the last war. Although many million of feet have been made, the real volume is still in the future. Today, such surfaced panels are still a premium specialty rather than a large volume utility product.

Fir plywood is advertised as the building material of a thousand uses. Overlay-faced panels can be used, of course, wherever regular plywood is used. Since they have premium faces, uses are necessarily limited to places where this is of distinct value. A large current outlet for masking overlays is in exterior siding. This application should and will be exploited to a greater extent with the increasing scarcity and expense of cedar and clear

TABLE 1—*Classification of paper-plastic overlays for plywood.*

Type	Purpose	Characteristics	Remarks
Masking	Mask minor defects, such as face checking, patches, grain pattern. Obtain uniform paintable surface. Permit upgrading of lower grade veneer. Extend wood supply.	Surface of uniform texture. Hardness and paintability at least equal to base wood. May be cut and worked as ordinary plywood.	Overlay paper has resin content of up to 25 percent and a thickness of from 15 to 50 mils. Masking usually achieved by application of one sheet only. Pressure not critical, but same as used for plywood manufacture. Potentially a low-cost utility overlay.
Decorative	Produce attractive and serviceable surfaces.	Surface of attractive color or design and highly resistant to liquids and abrasion. Surface requires no finishing or special maintenance.	Multisheet laminates of high-resin-content paper (30 to 70 percent), including a surface sheet of a decorative paper. Laminates usually pre-pressed and bonded to plywood core.
Structural (High density)	Increase strength, rigidity, and wear resistance of plywood. Improve surface of plywood and its resistance to water and water vapor.	Surface dense and hard, not necessarily smooth. May or may not mask grain. Appearance usually not decorative. Composite material strong and stiff. Resistant to water, water vapor, scuffing, and abrasion.	Paper thickness 3 to 10 mils, resin content 30 to 60 percent. Papers may be of high strength. Thickness of overlay from about 0.010 to 0.060 inch. Molding of paper to wood usually done in one operation, and self-bonded to wood at pressure less than the crushing pressure of the base wood.

[1] Based on a paper presented at meeting of the Forest Products Research Society, Pacific Northwest Section, November 14, 1951, at Longview, Washington.

[2] Bene, John. Douglas Fir Substitutes for the British Columbia Plywood Industry. Proceedings of the FPRS 4:328 (1950).

[3] Kotok, E. S. Peeler Log Potential of Southwestern Oregon. The timberman 51, No. 3: 46–47 (January, 1950).

[4] Seidl, R. J. Paper and Plastic Overlays for Veneer and Plywood. Proceedings of the FRPS 1:23–30 (1947).

fir siding. All-plywood railroad cars, truck bodies and trailers are using and will use increasing quantities of overlay-faced panels.

TABLE 2—*Types of masking overlays.*

Type	Remarks
Low density	10–20 percent resin content. Abrasion resistance equal to wood. Tough, high tensile strength. May be used on single veneers. Wet strength retention 60–70 percent. Excellent checking resistance. Can be molded or embossed. Most economical. Paint life improved over raw wood.
Medium density	20–40 percent resin content. Abrasion resistance better than wood. Not as good for single veneers because of brittleness. Wet strength retention 80–90 percent. Fair checking resistance. Too brittle for molding or embossing since it is pre-cured to prevent grain showing through.

Mr. Ritchie[5] of the Douglas Fir Plywood Association, has discussed the current marketing situation and availability of paper-plastic overlays. He pointed out that the production of plastic-faced Douglas-fir plywood was gaining in significance, because of the better utilization of raw material and the need for special products in a competitive market.

To give some idea of the growth that has taken place in the production of overlay plywood, the following figures are illustrative. In 1949, a total of 1,865 million square feet of fir plywood (3/8-inch basis) was manufactured, with 8.5 million square feet being produced with overlays. This represents a little less than 0.5 percent of total production. In 1950, a total of 2,550 million square feet were made, of which 33 million were with overlay, representing 1.3 percent of production. Last year total production was 2,867 million feet, with overlay production running at 1.5 percent of the total. So far this year total production is at the rate of 3,000 million feet with the percentage of overlay holding at 1.5 percent of the total.

This growth in importance of overlay-faced plywood has been recognized by the Douglas Fir Plywood Association by setting up their Allied Products Department. This group has devised uniform testing procedures for overlay panels. A uniform trade mark for certification of quality for such products is being used. A long term promotional and educational program is underway to inform the ultimate consumer of the value of these new materials.

Another development that bears watching, and which is not covered in the above classifications, is the use of hardboards as a masking overlay, or in some cases, actually a substitution for the face veneer. Although the cost is higher than a paper-plastic combination a more thorough masking job can be done because of the greater bulk and rigidity of the hardboard.

[5] Ritchie, John D. Future of Plastic Surfaced Douglas Fir Plywood. Proceedings of the FPRS 4:347–351 (1950).

Forest Products Laboratory Research

The Forest Products Laboratory at Madison has done considerable research on paper-plastic overlays of the low density type in the past few years and is currently expanding its investigation in this field. Several years ago the Laboratory prepared a series of overlay papers containing 0, 10, 20, 30, and 40 percent phenolic resin, applied to the paper by impregnation. These were bonded to fir panels and painted with various paint systems. After several years of exposure the papers with no resin have disintegrated, while the others are still sound. Compared to raw plywood control panels, the paint films have a much better appearance on the overlaid panels. This test is continuing and a final evaluation is yet to be made.

An overlay testing program now underway at the Forest Products Laboratory is entitled "Paper Plastic Overlays for Defective Douglas Fir Plywood and Plywood of Little Used Species." Douglas-fir infected with white pocket and Pacific silver fir *(Abies amabilis)* are the woods being used. The latter contains many knots, burls, and bark pockets. Panels are being prepared using several types of masking overlays. For each type of log, veneers are cut and panels made representing:

1. Slow growth. 2. Fast growth. 3a. White pocket rot, 10 percent rot. 3b. White pocket rot, 50 percent rot. 4. BB grade Douglas-fir for control panels.

The defects included in these panels were:

1. 1/8-inch split, tapering to 0 across panel. 2. 1/4-inch split, tapering to 0 across panel. 3. 1/2-inch knot hole. 4. Sound knot, less than 1 inch. 5. Cookie patch. 6. Rough cut veneer.

Both exterior and interior type panels are being made. The edges of the panels are being sealed, the faces primed, followed by two coats of paint. The exterior panels are being mounted on a test fence and are to be evaluated for performance once a year. At this time no one can say for sure what kind of defects can be tolerated under an overlay after several years exposure, but this program should supply the answers.

Crown Zellerbach Experience

Our organization became interested in the plywood overlay field in the years immediately after the recent war. Our first function was that of a supplier of paper board to various concerns that were treating this stock with thermosetting resins to prepare plywood overlays. Several sizeable runs were made, but, for one reason or another, these developments never materialized into full fledged commercial products. Our initial market surveys assured us that this field merited careful study and that because of our location and contracts here in the Pacific Northwest, we should strive to develop and produce a useful product for plants in this area.

When research was first started, the only satisfactory method available of introducing resins into paper was by a secondary converting operation; an impregnation process. Although a sheet with fair masking properties could be prepared by this process, certain defects were evident. Some resin migration always took place, leaving the sheet starved of resin in the center. Although we were able to reduce the effect appreciably, resin distribution was not as uniform as desired. This secondary treatment made it a more costly operation, and specially constructed impregnation equipment would be required. Before applying an impregnated sheet to a plywood panel, the resin had to be pre-cured, since otherwise the resin would flow while under heat and pressure in the plywood press and spoil the masking. It was found that such pre-cured sheets had very poor water resistance.

Because of the apparent inadequacies of overlays prepared by this process together with unfavorable economics, our attention next turned to the addition of resins at the beater. Early experiments were very disappointing, since resin retention in the pulp was very low. Several resin manufacturers tackled the problem of developing a practical beater-addition phenolic resin. At least two suitable resins are now available and our development of a low density masking overlay (termed Rezon BL-200 masking overlay) was made possible by the availability of these materials.

The use of beater addition resins provide a sheet with several unique properties. The resin is deposited uniformly throughout the sheet and in a form that gives a high degree of water resistance. Masking is effectively accomplished by a combination of bridging the larger defects and molding into the smaller ones, to provide intimate contact for bonding. By using figured cauls, decorative designs may be pressed into the overlay surface during pressing. The sheet may be also post-formed after regular pressing with heated embossing rolls.

(Continued on page 68)

Modified Woods[1]

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MODIFIED WOOD is wood in solid form—assembled veneer or lumber—whose properties have been changed by physical or chemical methods. Excluded are those products to which preservatives have been added to enable wood to resist decay and attack by insects and those products to which chemicals have been added to improve the fire-resistant properties of wood.

The physical strength of the modified material as well as the effects of moisture on wood are of primary importance in developing properties of these materials. Forest Products Laboratory research that led to the development of modified wood was started in a search for methods for stabilizing the dimensions of wood. As is well known, the shrinking and swelling of wood due to changes in its moisture content is one of its less desirable properties. The Forest Products Laboratory has shown that the depositing of a large number of different materials from solution within the cell walls of the wood will cut down shrinkage materially by bulking of the fiber. Salt and sugar deposited from a water solution will accomplish this but, unfortunately, they are readily leached out of the wood. Waxes and stearates will permanently reduce the shrinkage of wood if they are deposited within the fiber from fiber-swelling solvents such as pyridine and cellosolve. When wood is treated with these materials in the molten form or dissolved in a petroleum solvent, they merely coat the fiber walls and cut down the rate of water absorption and swelling and shrinking. They do not, however, affect the final dimension changes under prolonged moist or dry exposure conditions. Water repellents that are used to protect millwork temporarily before painting are of this type.

Stabilization Methods

Research has shown that permanent dimensional stabilization of wood can be accomplished in three ways.

1. *Bulking the fiber.*—By depositing such materials as fiber-penetrating resins or bulky acetyl groups within the cell walls and thereby effectively decreasing the shrinkage of wood by as much as 75 percent.

2. *Decreasing the hygroscopicity of wood.*—By chemically changing the wood; for example, by converting the hemicelluloses by heat to a water-insoluble material that has a reduced affinity for water.

3. *Cross linkage.*—By reacting wood with such substances as formaldehyde, which replace hydroxyl groups on two adjacent cellulose chains and tie them together. In this way, high dimensional stability can be attained with as little as 2 percent of chemical. Unfortunately, the formaldehyde reaction takes place at a pH of 1 or lower, which causes sufficient hydrolysis to reduce greatly the strength of the wood.

Misconceptions Prevalent

There are two major misconceptions concerning modified wood that have been prevalent. One is that lumber-size material can be stabilized. This is not practical. It is difficult to obtain uniform penetration of the chemical into lumber. Face penetration into heartwood under pressure rarely exceeds one-fourth inch. Diffusion into wet wood will reach greater depths, but it is exceedingly slow, varying inversely as the square of the thickness. Since the treating material is generally dissolved in a water medium, the drying or removal of the solvent is a problem. Offhand, one would not expect this to be more complicated than the seasoning of green lumber. The resin used, however, will tend to clog up the "pores" and greatly slow down the rate of water removal. As air has been appreciably removed from the wood and replaced by water, the tendency for the fibers to collapse on drying is accentuated, thus requiring prohibitively slow drying schedules.

The other misconception is that the resin with which wood is impregnated greatly affects the strength properties of the wood. This is not true, for the strength properties in general increase in proportion to the density or to a lesser degree. Sugar pine, for example, when treated with 30 percent resin, has its hardness increased approximately 50 percent. This may seem to be a significant increase. It would, however, have to be increased by 350 percent in order to attain the hardness of sugar maple. The resin added to wood is a bulking agent, and, since resin is not so strong as wood, it actually will weaken the material. The great increase in strength properties of the compressed materials is due directly to the compression of the wood.

Types of Modified Wood

There are, in general, two kinds or types of modified woods, those involving the addition of some other material to the wood, and those involving modification of the wood itself by physical or chemical means.

Representing the first type is impreg, which is wood impregnated with a resin, a water-soluble A-stage or low-molecular-weight compound. Urea-formaldehyde resins have been used and greatly publicized for their dimensional stability, which is the property of importance in impreg, but they are only about half as effective as the phenolic resins. Urea resins are used currently in some dry-formed board or molded products for interior use only. In this field, they seem to fill a need. Stabilities have been obtained with phenolic resins in which the dimensional changes under equilibrium conditions are only 30 percent of the dimensional changes of untreated wood.

Another product of this same type is acetylated wood, wood treated with acetic anhydride (a swelling agent) and a catalyst. The acetyl group reacts with the readily available hydroxyl groups, and dimensional stability results.

The last product in this type is compreg, which is resin-impregnated wood that has been compressed under controlled conditions of heat and pressure.

Representing the second type of product is staybwood, which is a product stabilized solely by heat.

Another product of this type is one the Forest Products Laboratory has termed staypak, which is a complex product in which the pasticizing agent is water. Strangely enough, in searching for a good plasticizing agent for wood, it was found that one of the best was a material already present in the wood, and that by proper conditioning and control of heat and pressure a permanent complex product was possible.

A detailed discussion of these various products follows.

[1] Presented at meeting of the Forest Products Research Society, Northeast Section, York, Pa., May 23, 1952.

[2] Maintained at Madison, Wisconsin, in cooperation with the University of Wisconsin.

Impreg

Originally, the Laboratory work on the impregnation of wood was with chemicals that will form a resin that will be polymerized within the cell walls of the wood. With the development of resins, low-molecular-weight A-stage resins that were water-soluble and could diffuse readily into the cell wall and subsequently be polymerized in place became available. If the polymerization advances to the B-stage, then the resin will not penetrate into the cell walls and is no more effective than such materials in nonswelling solvents. They can thus merely reduce the rate of swelling and not the final equilibrium. A water-soluble resin should be used rather than an alcohol-soluble resin if high dimensional stability is sought. The methods of impregnating wood with resin are four in number.

1. *Soaking in an aqueous phenol-formaldehyde resin generally containing 30 percent solids.* Green wood is preferable because the resin will diffuse most readily into green swollen wood. In thin veneers the amount of moisture present is not critical because sufficient solution will be taken up by capillary action to swell the wood structure. This method is slow. A 16-hour soaking period would be required for 1/8-inch veneer of many species.

2. *Immersing the wood under pressure in a solution of the resin in a pressure vessel.* This is a more rapid means that involves either pulling a vacuum or applying a pressure on the equipment. Very little improvement in the treatment is obtained when a vacuum is applied prior to the application of pressure, and the procedure results in a loss of the more volatile compounds. The most satisfactory procedure is to immerse the veneer in the resin solution so that each sheet is wetted as it is immersed and held below the surface of the liquid. Pressures from 25 to 100 pounds per square inch are required for 15 minutes to 5 hours, depending upon the thickness and species of the material under treatment. Cottonwood in 1/16-inch thickness can be treated in 15 minutes at a pressure of 25 pounds per square inch, while birch of the same thickness requires 5 hours at 100 pounds per square inch. The quantity of the resin solution taken up by the wood should be about equal to the air-dry weight of the wood.

3. *Applying water-soluble phenolic resins with a glue spreader.* This procedure works only on the more permeable species and gives only low resin contents. The amount of resin taken up can be increased by putting the veneer through the glue spreader a number of times.

4. *Passing veneer through compression rolls in which the nip of the rolls is below the treating solution.* In this case, low-density air-dry veneer can be compressed to approximately half its original thickness and, as the compressed veneer expands as it emerges from the rolls, the treating solution is drawn into the wood. Readily treated species can be processed in 10 seconds.

After treatment by any of the four methods, veneer should be solid-stacked to allow the resin to diffuse into the wood structure. The time required will vary, depending upon the species treated.

After this diffusion period, the material should be dried at temperatures not to exceed 160° F. The temperature depends upon the time of drying. The moisture content after drying and before pressing should be between 2 and 6 percent. When using veneer, an application of glue is desirable between plies.

Impreg has been used for face plies on plywood in order to improve the weathering characteristics and paintability, since it decreases checking and grain raising. During World War II it was manufactured for limited military use for housings for electrical control equipment. It was used also as a facing material for a laminated aircraft-carrier decking that had a redwood core. In service tests it showed a superiority over edge-grain Douglas-fir. Impreg shows considerable resistance to all chemicals with the exception of strong alkalies. Contrary to many publicity claims, impregnation of wood with resin has a negligible effect on the fire resistance of the product. However, fire-retardant salts can be added in the impregnation process. The treatment with resin imparts considerable resistance to decay, termite, and marine-borer attacks. It has been shown that the decay resistance is not due to the presence of a toxic agent, but results either from the reduced hygroscopicity, which prevents sufficient water from entering the cell-wall structure to support decay, or from a chemical change within the wood, which no longer makes the wood susceptible to fungus attack.

The only strength properties of the wood that are significantly increased are hardness, compression strength, and stiffness perpendicular to the grain. In impreg, primary concern is with the dimensional stabilization of the material.

Acetylated Wood

Wood has been acetylated by the use of a swelling-agent catalyst and acetic anhydride. The first catalyst used that was also a swelling agent was pyridine, but its cost was such that recovery of the material was necessary and not too practical. Recent work has shown that potassium or sodium acetates may be used as catalysts. Current research is under way now at the Forest Products Laboratory. Since the reaction is one of esterification of only the available hydroxyl groups, 16 to 20 percent of chemical is required. By available hydroxyl groups is meant those that are on the surface of the crystallites or in the amorphous portion of the cellulose. If all the hydroxyl groups are to be acetylated, as is done in producing cellulose acetate for plastics, 45 percent of chemical would be required. Only those hydroxyl groups mentioned above that are exposed to moisture need, however, be blocked with acetyl groups. In other words, one-third to one-half of the total groups must be acetlylated. Since acetylation is a bulking phenomena with no cross linking, embrittlement of the treated material does not follow. The acetyl groups do not cross link and form a three-dimension network as do the phenolic resins. Again, the only concern is with the partial specific volume of the material added rather than with the number of molecules of the reagent. The treatment serves to keep the wood in a swollen condition.

Because of the high cost of acetylation, attempts have been made to treat only the surface of woods or face plies of plywood. This treatment has shown considerable promise, and, while the process slightly bleaches wood, the treated material does not turn so gray on weathering as does normal wood. The process also prevents surface checks and grain raising and is one of the most promising possibilities available. An example of a possible use would be in siding where the natural finish of the wood is desired. Considerable further research is needed, however, before the process can be made commercially practical.

Compreg

After the wood is treated with resin to produce impreg, the material may be compressed under controlled conditions prior to cure of the resin to form this product. When compressed to a specific gravity of 1.2 to 1.35 at a temperature of 300° F., pressures of 1,000 to 1,500 pounds per square inch are required. The moisture content should not be more than 2 percent, otherwise the material will check. There are two types of compreg now being produced by two companies. During World War II, there were at least six companies producing compreg products for the armed forces.

One type of compreg being produced contains 25 to 30 percent resin

and has high dimensional stability, with the swelling being decreased to about 25 percent of normal (an anti-shrink efficiency of 75 percent). Because of the high embrittlement of this product or its low shock resistance, a lower-resin-content compreg containing 5 to 10 percent resin has also been produced. This product could also be described as a low-resin staypak because it possesses the high toughness and resistance to impact or shock needed for such products as shuttles and picker sticks. The product is simpler to press than staypak because it may be pulled hot from the press and the drying problems encountered in the manufacture of staypak are not present.

The high-resin-content compreg is used for electrical insulators in high-tension lines and for cutlery handles, brush backs and handles, and miscellaneous products because of its decorative value, but its most promising and widest use is for tooling jigs and forming dies because of its light weight compared to metals, relatively low cost, and ease of repairing. Maintenance is also lower, and there is less scratching of the finished part. One plant has reported that its production has been increased as much as four times by the use of compreg instead of metal dies.

One method of using compreg would be in the gluing of metal to metal in points where it is difficult to apply pressure. Precompressed resin-treated veneer that has been compressed at temperatures insufficient to cure the resin and cooled before releasing the pressure, may, if held in a confined space, develop forces of 500 to 1,000 pounds per square inch in tending to expand when subsequently heated to cure the resin. In the precompressing, veneer heated to temperatures of 210° to 225° F. may be fed into a cold press and pressures of 1,000 to 1,500 pounds per square inch applied as the veneer cools. One company is currently using this technique to glue a flange onto a helicopter blade by expanding the precompressed veneer within the joint to make it tight. Actually, here instead of having metal glued to metal, metal is glued to compreg, which, in turn, is glued to metal. The Forest Products Laboratory had an experience in which ½-inch bolts placed on 8-inch centers were stripped on a mold as a result of the pressure applied from heating the confined veneer.

Staybwood

Heating wood to high temperatures such as 500° to 600° F. for a few minutes imparts considerable dimensional stability to wood, but unfortunately, the wood becomes embrittled and loses over half its toughness. This product, because of the loss of strength, is largely a laboratory curiosity.

Staypak

When wood conditioned to 10 percent moisture is heated to 330° F. under pressure of 1,500 to 2,000 pounds per square inch, it may be permanently compressed to a density of 1.3. Staypak, unfortunately, because of its moisture content of 8 to 10 percent, must be cooled in the press to prevent a blow-up by the steam pressure created within the wood. It is this difficulty of manufacture, coupled with the drying of the ends of the edges of the wood during the pressing process, resulting in unstabilized ends and edges, that makes the addition of a small amount of resin, approximately 5 percent, desirable. When this is done, both difficulties are corrected and the product may be pulled hot from the press with the end drying kept to a minimum. Largely because of difficulties of manufacture and the large amount of trim, staypak has not been commercially manufactured.

Outlook Promising

Certainly, there is a bright future for wood that is dimensionally stabilized. Work is still in progress at the Forest Products Laboratory along these lines. The most promising points of attack are to find a chemical that will cross link during the reaction taking place within the cell walls without causing degradation of the wood itself. Because the Laboratory has obtained good dimensional stability with as little as 2 percent of formaldehyde by this process, it is believed that such a treatment could be made practical if the accompanying strength losses could be avoided. At present, the Laboratory is seeking other cross-linking chemicals. The major problem of finding simple and low-cost treatments applicable to all sizes of wood has not been solved. Because of the importance of dimensional stabilization of wood for many uses, the problem deserves further intensive study.

Discussion

Question—Can low-grade wood be used to produce these products? What is the effect of defects in wood?

Mr. Locke—Yes. Low-grade wood can be used to produce modified woods. In general, most of the strength properties are dependent on the density of the material rather than on species of wood. Since modified woods are made of thin laminations such as veneer, the effect of knots is not appreciable. The individual knots would be dispersed within the final product. However, if a uniform color is desired in the product, then clear defect-free wood should be used and there should be no voids between pieces of veneer in the core. If there are voids either in cross-banded or in parallel laminated compreg light lines will appear. If knot holes are present in the veneer, a light spot will appear. Where knots are present, dark spots probably would appear because of the greater density of the material in the knot area.

Question—Is compreg resistant to acids and alkalies?

Locke—Tests made at the Laboratory show that compreg is highly resistant to acids but not to alkalie .

Question—Which of these modified woods appears to be the most promising for general use?

Locke—At the present time, resi. - treated compressed wood (compreg) appears to be the most promising for general use. It is the only product that is now produced commercially. Acetylated wood shows considerable promise. The present methods for acetylating wood are too costly and new techniques must be developed to bring the process to commercial production.

Question (Paul Graham)—Do you need special cutting tools for machining compreg?

Locke—The same sort of tools are required for cutting or machining compreg as are required for most types of plastics.

Question (P. F. DeSaix)—What are the abrasion-resistant properties of compreg?

Locke—The wear resistance of modified wood varies with specific gravity. In general, an increase in specific gravity provides an increase in wear resistance. Compressed resin-impregnated wood having a specific gravity greater than 1.0 is more resistant to abrasive wear than compressed untreated wood of corresponding species and density. However, at specific gravities less than 1.0, resin-impregnation slightly decreases the resistance of the wood to abrasion.

Question (Gardner)—What types of modified woods have greatest possibilities?

Locke—Acetylated wood, because of its ease of treatment in the vapor phase and better properties, including an increase in toughness over compreg appears to have a bright future. The cost of producing acetylated wood at present is too high, but if the cost could be lowered, a very useful product will be available. For staypak the future looks limited because of the difficulties involved in manufacture. It has the desired toughness but lacks the dimensional stability of the chemically

(Continued on page 69)

Better Glues From Peanut Meal[1]

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Introduction

IN INDIA, peanuts are produced in very large quantities. They are extensively used for the production of oil, and peanut meal is extensively used as cattle feed. As imported plywood glue is quite expensive and since its cost limits the expansion of the plywood industry in that country, the manufacture of a high grade of glue from peanut meal would be of substantial economic importance. The writer has therefore investigated the possibility of improving peanut meals for this purpose by fermentation processes.

Mode of Diastase Action

The effectiveness of barley diastase in causing protein enrichment seems to be due to its ability to break down a large amount of carbohydrates without peptizing the protein to a high degree as fermentation progresses, and it differs in this respect from many of the other enzymatic preparations that have been tested. Treatment at 50 degrees C., with barley diastase produces the highest protein increment in fermented peanut meals regardless of origin.

The pH of the meal suspensions drifts progressively during fermentation toward the isoelectric point of the peanut protein; (i.e., pH 4 to 5) which, in addition to the effect of heat, contributes to the coagulation of the peptized protein. This drift in pH appears to be due to phototropic changes brought about by the dipolar ionic nature of protein complexes. Due to the same ionic exchange reactions of protein complexes, the addition of buffers will not stabilize the pH of meal suspensions. The pH drift is also beneficial to enzymatic activity, as at certain stages it corresponds to the optimum pH for most of the amylase preparations. The use of buffers in the fermentation of peanut meals by barley diastase is therefore unnecessary, as no appreciable improvement in protein enrichment through their use is obtained.

For proper protein enrichment, it is advisable to remove the residual lipid content of peanut meal by extraction with petroleum ether prior to fermentation. The amount of meal recoverable after fermentation depends upon the degree of protein enrichment. Generally, after 16 to 24 hours of fermentation with barley diastase, 65 percent to 70 percent of the original meal is recoverable. During fermentation, the protein is considerably denatured, as measured by its solubility in a molar solution of sodium chloride. This is caused, apparently, by the heat and the acidity that develops. Denaturation increases progressively during the first 16 hours of fermentation and then remains steady during the ensuing 8 hours.

Autolysis of meals (i.e., digestion of meals with water alone under the same reaction conditions as those followed in the fermentation process) produces a protein enrichment of from 10.7 percent to 12.4 percent. This lower protein enrichment in autolyzed meals is unquestionably due to the incomplete removal of the carbohydrates. During autolysis, these are broken down into dextrins of high molecular dimensions, whereas during fermentation the carbohydrates are hydrolyzed into reducing sugars. The same gradual increment of protein, decrease of loss of protein into the supernatant liquid, drift in pH and denaturation of protein as observed during fermentation occurs during autolysis. This indicates that the meal itself is responsible for the pH drift, rather than the fermenting enzymes that may be added.

Adhesive Characteristics of Protein-Enriched Peanut Meals

Enrichment of the protein in peanut meals to the extent of 12 to 14 percent, as accomplished by fermentation, assures higher strength and water-resistance in glues compounded from such meals. Glues prepared by conventional formulae from isolated peanut protein (96.85 percent) containing 16.25 percent peptizable protein gave dry strengths ranging from 350 to 440 psi. and wet strengths of 190 to 205 psi. It seems apparent, therefore, that the so-called denaturation of meals as measured by the solubility of the protein in a molar solution of sodium chloride is not a suitable criterion in evaluating the probable performance of glues prepared from peanut meals.

The working life (more than 3 hours), practical closed assembly periods (more than 15 minutes), and other considerations indicate that peanut meals enriched by fermentation can be used in formulating glues for commercial operations. The dry and wet shear strengths of protein-enriched peanut meal glues were found to be higher than those of standard commercial soya-bean glues.

[1] A contributed paper to the Journal of the Forest Products Research Society.

[2] In a research conducted while a graduate student of the College of Forestry of the University of Washington, certain conclusions regarding the necessity of properly preparing peanut meals for plywood glue manufacture were reached. The following short summary is condensed from a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Physico-Chemical Methods For Wood Diagnosis[1]

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WOOD IDENTIFICATION with the aid of a microscope has become universally accepted as the most reliable method for distinguishing and classifying the various species. Since wood structure has remained unchanged through the ages it is understandable that men began to observe certain anatomical differences in the various kinds of woods, and that these characteristics later contributed to the establishment of a taxonomic system *(5, 13)*.[2]

When two different woods of known species appear identical under the microscope, yet can be separated by chemical means, it stimulates thought in a new direction. As an example, the woods of pond pine, *Pinus rigida serotina,* and sand pine, *P. clausa,* are not distinguishable on the basis of anatomy, color, odor, taste, weight, or any other known physical property, although they are readily separated by a simple chemical test. Such a discovery may never contribute anything of commercial importance, but it is interesting scientifically and could well be visualized as having some future value, for example, in a legal case. When shavings from the sapwood of pond pine were placed in one test tube and shavings from sand pine in another a purple color reaction could be obtained in the former by adding methanol-hydrochloric acid *(8)*, whereas the same reagent would produce no change of color in the latter. This test, among others mentioned subsequently, was repeated successfully in the Timber Engineering Company Research Laboratory.

Other interesting findings by the same authors, using 25 parts of concentrated hydrochloric acid mixed with 1,000 parts of methanol as a reagent are as follows: All species of *Acer* except *A, negundo,* box elder, gave an intense purple color. *Quercus* species in the red oak group, with several exceptions gave a purple test in both sapwood and heartwood; but the heartwood of white oaks gave no reaction. Among three elms there was a noticeable difference in heartwood chemical consistency. Slippery elm, *Ulmus fulva,* gave a strong purple color; rock elm, *U. thomasi,* a faint color and white elm, *U. americana,* was colorless.

Differentiation of Gums

More recent tests have shown that a reagent composed of equal parts of methanol-hydrochloric acid has at least one practical commercial application in wood technology. During pilot plant tests on the one-step process for seasoning and creosoting of railroad crossties conducted by Timber Engineering Company chemists at the Santa Fe railroad's Albuquerque, N. Mex., treating plant several species of ties were scheduled in the extensive tests. Among those presenting the greatest problem of species separation were black gum, *Nyssa sylvatica* and sap gum, *Liquidambar styraciflua.* Yard employees who were unfamiliar with these two species were instructed by the chemists to apply a small paint-brush dab of the chemical to a clean section along the side of each gum tie. The results eliminated all possibility of error in identification since the sap gum, upon arrival at the retort, showed a brilliant purple spot where the chemical was applied, while no evidence of color could be observed on the black gum ties. It should be noted, however, that the wood of all these test ties was unseasoned. Similar methods employed on the same two species in a thoroughly dry condition are less reliable because the purple color on the sap gum does not develop with sufficient intensity as to be unmistakable. This is difficult to explain in view of the observations of Isenberg and Buchanan *(8)*, who found that in testing samples of green wood the higher moisture content tended to dilute the methanol and interfered with the color reaction.

Detection of Infecting Organisms

The first diagnostic use of acidified methanol on wood was apparently that by Hutchins *(7)* for distinguishing virus-infected wood from sound. He immersed thin transverse sections of roots of peach trees in absolute methyl alcohol acidulated by 1 to 5 drops of CP concentrated hydrochloric acid per 25 cc. In 5 minutes wood from trees infected with the virus of phony disease showed numerous purple spots, which did not appear on healthy wood. This discovery was put to extensive practical use in the detection of infected trees in the eradication campaign that prevented the destruction of the Georgia peach industry. Ken Knight *(8a)* recently reported an improved test on peach root wood with a freshly prepared mixture consisting of 10 parts of a solution of zinc chloride saturated at 20° C. and 1 part each of 2 percent phloroglucinol and 20 percent hydrochloric acid. The gum in the virus-infected wood turns red under this reagent. The new test also detects wood of peach and plum infected with the peach rosette virus.

Possibilities of the Method

On the shelves of our chemistry laboratories there are doubtless many other reagents yet untried. This suggests a fascinating field, worthy of investigation. Literature on the subject is practically nil. The authors of this paper have seen enough to be convinced that it may be entirely possible to separate such woods as western hemlock from true firs, certain oaks from others within the same group, or possibly additional individual species of pines among the southern yellow pines. It would be helpful to have a reliable test for separating eastern white pine from western, Engelmann spruce from the eastern spruces, or to isolate one or more of the ashes, hickories, and other generic groups within which the microscope (or our knowledge of its use) has reached its limits.

Work With Fluorescence

In the sixteenth century the Spanish physician Monardes described a white wood brought from New Spain (Mexico), which produced a blue fluorescent infusion when chips were allowed to soak in a container of pure spring water. This was said to be a wonderful remedy for kidney ailments and consequently the name *"Lignum Nephriticum"* was applied. The identity of the species described by Monardes, and subsequently by many other physicians, priests, and early scientists, remained a mystery for approximately 300 years. Safford *(14)* describes, in an interesting paper, how he traced the wood to two widely separated species, one from Mexico *(Eysenhardtia polystachya)*, the other from the Philippines *(Pterocarpus indicus)*. Turned cups made from

[1] A contributed paper to the Journal of the Forest Products Research Society.

[2] Numbers in parentheses refer to literature cited at end of paper.

either one of these woods, and simply filled with pure water, exhibited a remarkable blue fluorescent color on the surface. According to the account, *Eysenhardtia* proved to have such remarkable fluorescing power that an extract of one part of wood in a hundred thousand parts of water (on the alkaline side) produced a distinct fluorescence.

Several years ago W. N. Watkins of the Smithsonian Institute demonstrated to Stearns the value of ammonia water in the identification of the so-called "Dragon's blood wood" from southern India *(Pterocarpus santalinas)*. A few milliliters poured into a test tube containing shavings of the dark ruby-red wood produced a deep blue fluorescence almost immediately.

The Forest Products Laboratory *(10)* has investigated the advantages of fluorescent stains as applied to wood sections. The procedure, as developed at the laboratory during a study of oak specimens, was by incident-light fluorescence microscopy on the smoothed surface of small blocks. Following the tests several advantages were claimed for the new technique, first of which was that reliable recognition of anatomical characteristics in wood could be determined without ordinary time-consuming histological techniques.

Ultra violet light rays produce fluorescence on certain other species of wood and bark as well as the infusions of the species mentioned above. It was found that the inner bark of black oak, *Quercus velutina,* was fluorescent under a black light *(17)*. Knowledge of this will prove useful in distinguishing this species from others in the red oak group whenever the specimens contain bark.

The authors have examined a considerable number of other dry wood species under ultra violet light, both with an inexpensive 250-watt General Electric black-light bulb, and in the case of some selected specimens, with more elaborate equipment, through the courtesy and cooperation of the Bureau of Standards in Washington. It was found that heartwood and in some cases bark of the following species produced a decided fluorescence:

Acacia farnesiana
Acacia moniliformis
Acacia peninsularis
Albizzia sp.
Berberis thunbergi
Cassia siamea
Dodonaea viscosa
Esenbeckia atata
Gleditsia triacanthos
Gymnocladus dioicus
Hibiscus syriacus
Mahonia trifoliata
Mahonia swaseyi
Microplumeria anomala
Piptadenia pseudo-flava
Piptadenia africana
Pistacia texana
Pistacia vera
Pistacia chinensis
Prunus virginiana demissa (bark)
Rhus aromatica
Rhus chinensis
Rhus copallina
Rhus copallina lanceolata
Rhus glabra
Rhus hirta
Rhus laurina
Rhus leucantha
Rhus vernix
Rhus virens
Robinia hartwigi
Robinia pseudoacacia
Robinia viscosa
Sorbus quercifolia (bark)
Virgilia oroboides
Vitex pubescens

The appearance of fluorescent wood surfaces under the ultra violet light is invariably a delightful surprise to those who observe it for the first time. For example, the plain reddish-brown heartwood of a species such as *Acacia farnesiana* becomes a brilliant gold under the light, and where sapwood is present this reflects the violet rays in complementary contrast.

The woods of the Angiosperms can be separated from those of the Gymnosperms by another chemical test *(11, 18)* called the Mäule reaction. It consists of treating the wood in question first by a thorough soaking in potassium permanganate solution then following with hydrochloric acid and finally with ammonia. If the specimen turns red it is an angiosperm; if yellowish or brownish, a gymnosperm. A variation of this test *(23)*, as developed at the Institute of Paper Chemistry consists of the use of chlorine water and sodium sulphite.

A central American wood closely resembling mahogany, called Carapa, Cedro Macho, or Crabwood *(Carapa guianensis)* can be distinguished from true mahogany *(Swietenia)* by another chemical test *(6)*. Fine shavings of the wood are placed in a test tube and about 20 cc. of distilled water is added. After 24 hours two or three drops of 3 percent ferric chloride are added. Carapa infusions are characterized by being colorless or pale, dull brown, changing relatively little in color after two to four days exposure to sunlight, and becoming a pale green color when the ferric chloride is added. The mahogany infusion, on the other hand, is a reddish amber, becoming bright brownish-red after two to four days exposure to sunlight and dark green upon adding the ferric solution. Pale green Carapa solutions tend to clear in a few minutes. Dark green *Swietenia* solutions tend to retain their color or get darker.

The oils in Jeffrey pine and ponderosa pine are so different that a chemical test is possible *(19)*. Jeffrey pine oil is 95 percent heptane, a hydrocarbon differing greatly from the terpenes found in ponderosa. The low specific gravity and boiling point of heptane permit ready identification and separation from terpene. Heptane boils at 98° C. and terpene at 156° C. There is no heptane present in ponderosa. The "varieties" of ponderosa all have the same chemical content as the true type of ponderosa and therefore, according to Schorger, this would indicate Jeffrey pine is a true species and that Jeffrey does not hybridize with ponderosa.

The woods of two Australian species, Hoop pine, *Araucaria cunninghami,* and Bunya pine, *A. bidwilli,* can be separated by another color reaction *(2)*. This consists of rasping the specimens to obtain wood particles, and screening these through a 20-mesh sieve. Five grains of this air-dry wood placed in a flask fitted with a reflux condenser and extracted two or three hours at a temperature of a boiling water bath with 50 cc. of water. After filtering and pressing, the wood is washed with 50 cc. of boiling water. This wash is added to the original extract. When cool, the volume of the extract is adjusted to 100 cc. To 2 cc. of aqueous extract in a test tube, 1 cc. of concentrated sulfuric acid is added to form a layer. This is mixed. In bunya pine a pink color will develop immediately, and an orange-colored precipitate will form (sometimes slowly). In Hoop pine there will be no immediate color change, but later a white gelatinous precipitate will form.

One of the most important distinctions is between the white and red oaks. The generally higher decay resistance of the white oaks is well known. All species of the white oak group that have been tested individually are significantly more decay resistant than the red oaks *(16–17)*, and the white oaks should be required for boat frames and all other long-time uses where oak without preservative impregnation is to be exposed to moisture. The red oaks, however, take preservative treatment better and are preferred where pressure treatment is practiced. While oak producers rarely make an error in distinguishing the two groups by inspection, a surprising number of experienced users are not so expert and very few are acquainted with the standard anatomical distinction between the two groups by the vessels in the summerwood, the most reliable criterion previously known

(21). In practice, red oak too often has been sold as white for use in ship frames, and, at the other extreme, white oak has been supplied as red for use in pressure-treated sheathing. In narrow-ringed red oak there is often too little summerwood to show the summer vessels, while, in very wide-ringed white oak, summer vessels are occasionally found that look so much like those of red oak as to deceive anyone not highly expert in the use of this test. The examination of a necessarily very smooth cross cut surface is not practicable, after oak has been end scarfed into a ship's keel or a laminated frame. Regardless of the ability of trained lumber inspectors, their opinions cannot be considered infallible under such circumstances. The distinction of the two oak groups where only side grain is visible, by brushing a chemical solution on the surface, is described in the following as a quicker and easier procedure in such situations and one requiring less expertness than the anatomical examination.

Differentiation of Oaks

The reagent used is the benzidine-sodium nitrite solution used earlier *(9, 22)* to distinguish heartwood from sapwood in the pines. Its distinctive reaction on red and white oak was first observed *(20)* during an investigation of chemical color change on about 300 species of hardwoods and softwoods, representing 28 families and 70 genera from different parts of the world. No important differences were obtained between species except in the oaks. The test was extended to the following oak species, which include most of the commercially important species in the United States:

White oaks

white, *Q. alba* L.
swamp white, *Q. bicolor* Willd.
Oregon white, *Q. garryana* Dougl.
overcup, *Q. lyrata* Walt.
bur, *Q. macrocarpa* Michx.
chestnut, *Q montana* Willd.
chinquapin, *Q muehlenbergii* Engl.
swamp chestnut, *Q. prinus* L.
post, *Q. stellata* Wangenh.
live, *Q. virginiana* Mill.[2]

Red oaks

Northern red, *Q. borealis* Michx.f.
scarlet, *Q. coccinea* Muenchh.
Southern red, *Q. falcata* Michx.
swamp red, *Q. falcata* var. *pagodaefolia* Ell.
turkey, *Q. laevis* Walt.
blackjack, *Q. marylandica* Muenchh.
water, *Q. nigra* L.
pin, *Q. palustris* Muenchh.
willow, *Q. phellos* L.
black, *Q. velutina* Lam.

[2]Live oak producing a color reaction as in the white oaks.

The Reagents

The reagent is composed of two separate solutions that are mixed in equal amounts before applying to the wood surface. They are:

Solution A. Five grams benzidine dissolved in 23 cc. (25 grams) of 25 percent hydrochloric (muriatic) acid and 970 grams (cc.) of water. (NOTE: CP hydrochloric acid is 37 to 38.5 percent hydrochloric acid; to make a 25 percent solution, pour out 25 cc. of the CP hydrochloric acid and add enough water to make 37 to 38.5 cc. of liquid.)

Solution B. A 10 percent solution of sodium nitrite. (Sodium nitrate will not do.)

Within 10 to 30 minutes after applying the chemical to the oak, a distinctive color develops. If that color is light to medium reddish-orange, the wood specimen is one of the red oaks. If the color is walnut or a dark greenish-brown, the specimen is a white oak.

Only small quantities of the solutions should be mixed at any one time. Within 2 hours a brown precipitate forms in the mixture. In spite of this, the reagent continues effective through a working day, but by the third day it no longer gives a good differentiation. A small brush or swab is satisfactory for applying the reagent. Application should be made to heartwood; on white oak sapwood the color of the reagent is too much like that on red oak to make a sharp test. The reagent should be used on a fairly smooth surface; the turned-up fibers on a rough-sawn white-oak face may show too much of the red oak color. Weathered surfaces should first be scraped. When painted faces are tested, the paint must be removed not only to the depth reached by the pigment, but as deep as the oils penetrate, in order to get a distinctive color. The same of course is true for surfaces that have been treated with a water repellent.

The advantages of the color test became apparent in examination of oak used in shipbuilding by members of the Division of Forest Pathology. It was possible to check more than 4,000 pieces at shipyards in much shorter time than it could have been done with knife and lens. On ships built some years ago, the color test made it possible to distinguish easily white and red oak framing members, with the result that decay was demonstrated to be more than twice as frequent in the red oak as in white. In the above use of the color reaction, pieces on which the color was not very sharply defined were also examined anatomically where possible, and the agreement between the two types of test was excellent.

It may be noted that after some days or months the dark color on white oak fades, returning on many specimens to the color shown on red oak. Some specimens fade much more quickly than others.

The 10 percent sodium nitrite solution alone was tried on the oak species in the foregoing list. It also distinguishes the two groups; the only failure was on live oak, which of course is not a typical white oak. The color during the first 15 to 30 minutes passes through brown-purple to a greenish- or bluish-gray; this is darker and with more of the bluish tinge on the white oaks than on the reds. The distinction is not quite as sharp as with the benzidine-nitrite mixture; of 23 red oak specimens tested, two showed enough green to approach closely the color obtained on the white oaks. The distinctive color on the white oaks fades sooner than with the benzidine mixture so that results of the test should be read before the end of the day on which the reagent is applied. The nitrite alone has the advantage that it can be used on rougher surfaces than the mixture, but its chief advantage is that it need not be made up fresh each day as does the mixture, and only a single bottle need be kept on hand. While the mixture is considered a somewhat better reagent, the greater convenience of the nitrite alone will commend it when only scattered tests are to be made.

A mixture was tested in which the benzidine was replaced by an equal concentration of p-nitroaniline-o-sulfonic acid, but this gave only the same reaction as the nitrite alone.

The reaction of the benzidine-nitrite does not appear to be the same on white oak heartwood as on pine, since on the pine heart the resultant color is very reddish, appears quickly, and is persistent. This contrasts with the slow darkening and ultimate fading that characterize the distinctive color on the white oaks.

Sapwood vs. Heartwood

In species with typical heartwood, it is usually so different in appearance from sapwood that differentiation requires no special aid. But there are numerous times when there is doubt. This is particularly true for example in laminating oak; in a piece that is part sapwood, the dividing line is usually fairly obvious, but pieces that are all sap, if somewhat darker than average, are sometimes mistaken even by experienced men for all heart, and accepted for such critical members as ship frames with consequent great increase in the decay hazard.

Chemical differentiation of sapwood and heartwood has been described for the pines, oaks and Douglas-fir *(22)*. For the oaks and Douglas-fir the reagents are acidity indicators applied directly to the wood surface. The greater acidity of the heartwood on which these tests depend is found in green wood in many genera. The sapwood goes in the acid

direction on drying, but in southern white cedar *(Chamaecyparis thyoides)* as in the oaks and fir, after seasoning the difference in acidity can still be used to distinguish heartwood from sapwood. Not only the Benzo Yellow, recommended for oak, and the Alizarin Red S, recommended for Douglas-fir, but also the Truog Triplex wide-range soil acidity indicator give a very sharp distinction between heart and sap of the cedar on a freshly exposed surface, on either side or end grain. Unfortunately there may be no appreciable difference on an old surface in the cedar, even if it is not visibly weathered. The Benzo Yellow test on oak was found equally distinctive for sapwood and heartwood of *Castanea crenata.*

In Douglas-fir plywood in which visual distinguishing of heart from sap is especially difficult, the Alizarin Red S is often unsatisfactory. On the plywood, the indicator too often shows everywhere the red tinge appropriate to sapwood. The reason in some cases is apparently that the glue has a pH above the critical point for the indicator. Careful removal of powdered glue that has been carried over the surface by cutting tools sometimes shows the center of the veneer to give the heartwood reaction. In other cases the entire thickness of the veneer gives the sapwood reaction, despite the fact that around 90 percent of typical Douglas-fir plywood is ordinarily heartwood. The Truog indicator however can be useful on plywood as a quick method for distinguishing interior plywood bonded with a high pH organic glue, from exterior types in which the more acid glues are used.

In several genera, contrasting with those mentioned in the foregoing, the heartwood or the outermost zone of it in the green condition is often wetter and less acid than the sapwood *(1, 3, 4, 12)*. In the elms and the true poplars, the outer heart is usually so much less acid that the boundary between sap and heart can be readily located by brushing the Truog indicator on end grain surfaces. Bacterial infection is associated with the wetwood condition and is presumably the cause of the lowered acidity in these genera and perhaps in others. In willow, birch, and maple, the lower acidity of the outer heart is sometimes quite striking, but is too variable or temporary to serve as a basis for distinguishing heart and sap. At least in aspen, the wetwood has some practical interest because of its tendency to collapse on kiln-drying *(3, 12)*. Both this collapsible zone and the mineral streaks in maple that dull tools can be recognized by their alkalinity to the Truog indicator. Hydrochloric acid produces visible effervescence from the carbonate deposits in real mineral streaks *(15)* and sometimes on wetwood in the poplars and elms.

Eades *(4A)* has examined the usefulness of iodine in distinguishing heart from sap.

The use of indicators to distinguish heart from sap may serve incidentally to distinguish species. As remarked by its originators *(9)*, the benzidine-nitrite reagent supplies a quick method of distinguishing pine from other softwoods of similar appearance, if both sap and heartwood are present in the specimen, since the reagent differentiates them only on pine. Somewhat similarly Hartley found the Truog indicator to distinguish, in the green condition, noble fir from western hemlock, in pieces in which both sap and heart are present. On end grain the fir showed a color reaction about one pH unit higher on the outermost heart than on the adjacent sapwood, while on the hemlock no such difference was observed.

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Occurrence and Probable Cause of Heartwood[1] Degradation in Commercial Species of Populus

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Prejudice against the discolored heartwood of aspen has long existed in many industries using this species. This discolored heartwood which also occurs in other species of POPULUS has been found to be weaker in toughness and compression strength and lower in specific gravity than the sapwood which surrounds it. Evidence indicates that this unusual phenomenon can be explained only by a new concept—the degradation of the heartwood in standing, living trees by bacteria which are always present in abundance.

IT IS GENERALLY RECOGNIZED that the heartwoods of practically all trees differ from their respective sapwoods in such physical and chemical properties as color, durability, presence and nature of extractives, perviousness, and often in density—due mainly to the presence of extractives and other infiltrated substances. With regard to mechanical properties, however, it is generally accepted that provided growth conditions and density are similar, there is no significant or important difference between the strength of the sound heartwood and sapwood of any of our commercially important tree species.

It was of considerable interest, therefore, when in connection with studies of the relationship between the strength properties of aspen (*Populus tremuloides* Michx.) and the commonly occurring defect known as "collapse," the writers and others *(5)* encountered evidence of brashness or weakness of aspen heartwood as compared to sapwood. There was no evidence of fungus decay in the material tested and there was every indication that the weakness in mechanical properties was characteristic for the species. The phenomenon could not be explained on the basis of existing principles or by known causes of such variations.

The further investigation of the occurrence and determination of the probable cause of this unusual difference in strength properties of aspen heartwood and sapwood were made the basis of this study. The study was stimulated by the discovery that the clear white sapwood of aspen is generally considered superior to heartwood for many uses, thus further indicating the possibility of existing significant difference in strength properties. In the later stages of the study it was extended to other species of the genus.

Literature

In studying heartrot in aspen, Schmitz and Jackson *(13)* concluded that the common discoloration of aspen heartwood was caused directly by wood-destroying fungi. They believed the rather common occurrence of bacteria, which they found to be almost as prevalent as wood-destroying fungi, was interesting, but they did not connect the bacteria with the discoloration.

Johnson, Kittredge and Schmitz (9) in microscopic examination of dark, discolored wood around aspen knots could find no sign of fungus action, in spite of the fact that this dark color has been ascribed to the action of wood-destroying fungi.

According to Crandall, Hartley, and Davidson (6) bacteria have been reported in the wood of nine species of *Populus,* as well as in eight other genera of trees. Hartley and Crandall *(8)* found that a short, rod-shaped, gas-forming bacterium kills lombardy poplar. Carter *(4)* found a similar condition in his study of "wetwood" in American elm.

Dadswell and Langlands *(7)* in discussing "brittle heart" in species of the genus *Eucalyptus* have defined it as that central portion of the tree which is extremely brittle and of comparatively low impact strength. They observed that material isolated by maceration of the wood from "brittle heart" was characterized by a large percentage of broken fibers, the breaks being approximately at 90° to the long axis of the fiber, and that minute compression failures were very common in the area of "brittle heart" close to the center of the tree. Also, this wood tends to collapse more than the sound wood on the outside. They concluded that incipient decay is responsible for the various properties of "brittle heart." Rendle *(12)* argues with this explanation, stating that it is hard to understand how decay alone can account for the large proportion of broken fibers which were found, and that a force acting on a mature tree could not fracture the fibers of the weak central core without permanently affecting the sound tissues of the outer layers. I. H. Boas (3) states that "brittle heart is almost certainly present in the hardwood timbers of the Northern Hemisphere, although probably not recognized as such." Tieman *(14)* states that no attention has been paid to the distinction between "true wood" and "brittle heart" in America and suggests that an investigation of it in domestic woods would be valuable.

Materials and Methods

The species included in this investigation of discolored heartwood in the genus *Populus* were aspen, *P. tremuloides* Michx.; balsam poplar, *P. tacamahaca* Mill.; cottonwood, *P. deltoides* L.; and largetooth aspen, *P. grandidentata* Michx.

Source of Material and Methods of Sampling

In the spring of 1949, 22 aspen logs were obtained from the Diamond Match Company, Cloquet, Minnesota. All of these logs came from material which was logged the previous winter in the general region of Orr, Minnesota, an area noted for its production of high quality aspen. Log samples were selected at random from material moving into the cut-up room over live rolls. All logs contained at least some heartwood. Only logs that appeared to be sound and free from decay and other serious defects were chosen. Two-foot long sections were cut from near the center of each log so that the end effect would be minimized. All test specimens were cut from these two-foot sections.

Log samples from three balsam poplar, two cottonwood, and two largetooth aspen trees were also included in the investigation. These samples were taken in the form of 30-inch sections from about 10 feet from the base of trees, all of which were alive and standing at the time of sampling.

Testing Procedures Used

In reducing the tree sections to test specimens, disks 2½ inches long were removed from the ends of each section and discarded in order to further reduce the possibility of end drying. Another disk 1 inch thick was then taken for ring counts, moisture content determinations, microorganism isolations, and maceration studies. The remaining portion of each bolt was then separated into heartwood and sapwood by the use of bolt and table saws. The resulting pieces of wood

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were reduced to toughness and compression test specimens. Whenever possible, 25 toughness and 25 compression specimens were made from each of the heartwood and sapwood zones.

Moisture content determinations were made on pieces split from the one-inch-square strip taken from the diameter of the disk, paying close attention to the limits of heartwood and sapwood.

Isolations of microorganisms were made by surface sterilizing the radial surface of the unused half of the one-inch disk by the alcohol-flaming method and placing small sections from this surface by sterile technique onto nutrient media. Both malt agar and bacto beef agar were used in order that either bacteria or woodrotting fungi would appear if present in the wood. Five cultures on each media were made from each of the heartwood and sapwood zones of each log. The cultures were read approximately one week after being prepared. Total number of cultures, number containing bacteria, number containing woodrotters, and number sterile were recorded.

The average number of rings per inch was determined for the sapwood and heartwood.

Specimens used for strength determinations were prepared by sawing to approximate and planing to desired dimensions. Toughness specimens were made 5/8 by 5/8 by 10 inches and compression specimens were cut 1 by 1 by 2 inches along the grain.

Compressive strength tests parallel to the grain were made on a Southwark Tate-Emery testing machine. The blocks were compressed at the rate of .024 inches per minute to maximum crushing strength. Only the maximum compression strength was recorded. For toughness strength determinations a standard Forest Products Laboratory toughness testing machine was used and toughness values were taken from Forest Products Laboratory Report No. 1308 *(2)*.

Specific gravity determinations, based on volume when green, were made on five compression test samples from each zone of each log.

Experimental Results

Moisture Content

Moisture content determinations are not included in this report in table form since they were made only to check whether or not the moisture content was above the fiber saturation point. All the moisture content determinations made showed that the material used for mechanical tests was well above the fiber saturation point and in the same range as that reported on in an earlier publication *(5)*.

Microorganisms

Of all the logs tested, only one was found to contain a wood-rotting fungus, and in this log (aspen number 18) it occupied only a limited region in one part of the log. The remaining aspen bolts were found rather uniformly infected with bacteria and bacterial cultures were obtained from all of these containing "wetwood"[2] and distinct heartwood. All log sections of species other than aspen were found to contain bacteria and bacterial cultures were obtained from every section tested. Bacterial cultures were obtained in a higher percentage from the heartwood than from the sapwood.

Increment Growth

In Table 1 are shown the data obtained on increment growth of all logs included in the tests. From this table it may readily be seen that with few exceptions, the values in the "rings per inch in the sapwood" column exceed the corresponding values in the "rings per inch in the heartwood" column. This relationship holds true for all species tested.

TABLE 1—*Results of ring count study in all species.*

Log No.	Rings per inch of diameter	
	Heartwood	Sapwood
Aspen		
1	10.5	13.5
2	9.4	14.2
3	8.6	16.2
4	7.3	8.7
5	12.8	12.5
6	8.0	10.0
7	10.9	10.4
8	5.6	5.8
9	10.5	12.0
10	11.0	16.5
11	6.5	6.1
12	10.0	14.0
13	7.6	9.1
14	6.3	6.7
15	7.4	13.6
16	10.0	22.2
17	11.6	12.7
18	10.5	14.4
19	9.1	11.4
20	7.3	6.3
21	8.8	11.2
22	6.4	9.7
Balsam Poplar		
1	13.6	13.1
2	13.1	17.4
3	6.0	9.3
Cottonwood		
1	3.5	4.5
2	3.9	3.7
Largetooth Aspen		
1	9.5	17.2
2	7.6	19.4

Specific Gravity

Figure 1 is a graphical presentation of the data on specific gravity of aspen sapwood and heartwood which shows the variation found between the two zones for the individual logs. The method of preparation used was to arrange in order of magnitude all of the sapwood specific gravity averages for the individual logs and beginning with the highest, plotting the next lower value one unit to the right of it. After plotting all of the sapwood values and placing under each its log number, the corresponding heartwood averages were plotted in the same vertical plane. The connecting lines between points do not represent any trend; they merely connect the individual log values for heartwood and sapwood into separate groups.

The horizontal lines represent the grand averages for each of the two zones. From Figure 1 it may be seen at a glance that in all except four of the 22 sets of averages plotted the sapwood values exceed those of the heartwood. The average difference is .020. In those four logs in which the heartwood specific gravity exceeded that of the sapwood, the actual differences were very small, never exceeding half of the average difference between average sapwood and heartwood grand averages.

Similar specific gravity data for other species tested appear in Table 2. In each log of each of these species specific gravity of the sapwood exceeded that of the heartwood zone.

Compression Strength

Figure 2 shows graphically the relationship between maximum compression strength for aspen heartwood and sapwood in the same manner that Figure 1 does for specific gravity differences. Here again it must be remembered that the only relationships shown are the individual differences between the heartwood and sapwood of individual logs and the grand average maximum compression values for each. Without exception, the maximum compression strength of the sapwood of aspen was greater than that of the heartwood and the average difference was 271 psi. The relationship between compressive strength of sapwood and heartwood of balsam poplar, cottonwood and largetooth aspen was considerably more striking than for the above group of aspen logs, the differences being 20.7, 58.8, and 36.5 percent, respectively. Results of compression tests on species other than aspen appear in Table 2.

Toughness

Figure 3 shows graphically the comparative toughness of aspen heartwood and sapwood. Similar data for other species tested appear in Table 2. Figure 3 was prepared in the same way, and should be used in the same manner as Figures 1 and 2. As was the case with compression strength, the average toughness value for the sap-

[2] The term "wetwood" has been used by the authors *(5)* and others to distinguish the zone of high-moisture-content wood, commonly found in aspen and other species of *Populus*, between the heart- and sapwood. In this paper, however, this "wetwood" zone is considered as heartwood and it was not separated from the heartwood.

wood of each log of each species exceeded that of the heartwood and the average reduction in toughness of aspen heartwood over sapwood was 44.3 inch-pounds or 32.4 percent. Grand averages for all individual sapwood and heartwood averages are represented by the horizontal lines.

In addition to the quantitative measure of toughness, the type or quality of failure (e. g. splintering, brittle) was also recorded for each toughness specimen. This type of empirical data does not lend itself to summarization in tabular form, but the following general statement can be made: A high percentage of all sapwood specimens of all species failed with a splintering type of failure while the heartwood samples gave a high percentage of brittle or brash failures. There were few brash failures in the sapwood. This difference in type of fracture is shown in Figure 6.

Maceration of Material

The author was unable to distinguish through microscopic examination of macerated material any appreciable difference in the percentage of broken fibers between the heartwood and sapwood. Neither zone had what might be considered typical broken fibers of the type observed in certain Australian species by Dadswell and Langlands *(7)*.

Analysis and Discussion of Results

Microorganism Infection

In all cases the bacteria isolated from the various species produced slimy cream colored colonies on malt agar and slightly darker colonies on beef-peptone agar. From macroscopic observation all colonies appeared to consist of a single species.

The failure to obtain wood-rotting fungi in isolations from the logs (with the exception of one log) is rather positive evidence that the heartwood, as well as the sapwood, was free from wood-destroying fungi and that the strength reduction observed cannot be attributed to decay. Microscopic examinations of sections cut from the logs likewise failed to reveal evidence of wood rotting fungi. The ease with which bacterial cultures may be isolated from the heartwood of almost any live aspen tree indicates the close association of these organisms with aspen "wetwood" and heartwood formation. The isolation of bacteria from the heartwood of all logs sampled in an earlier study (5) would likewise lend credence to the suggestion that bacteria are almost universally present in aspen "wetwood" and heartwood, and may be common even in sapwood.

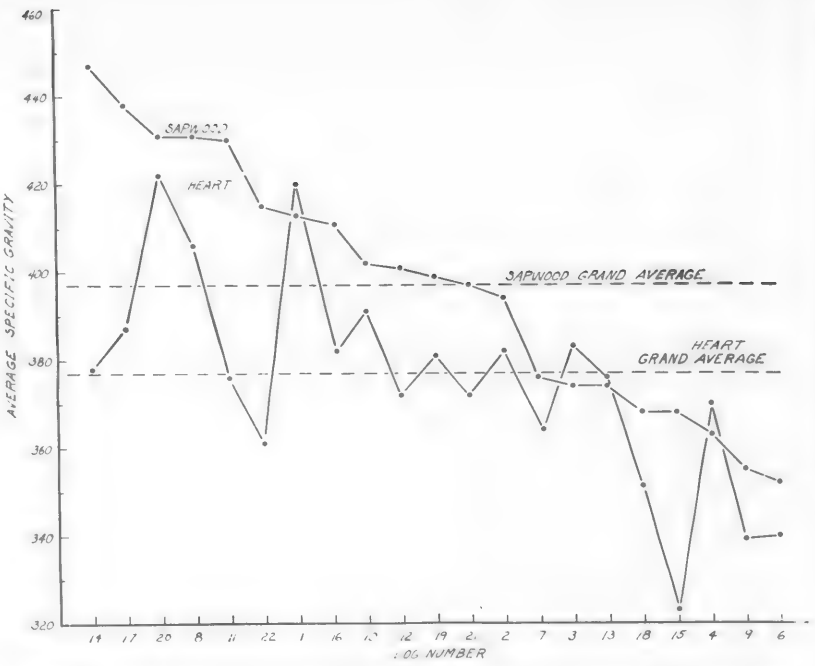

Figure 1.—Comparison of the specific gravities of heart- and sapwood in 22 aspen logs.

Significance of the Variations in Physical Properties

In order to ascertain statistically the probability of obtaining the variations in specific gravity, compression strength and toughness between the heartwood and sapwood zones of aspen logs as a result of sampling error, the "t" test of significance was applied to each group of data. The results of this analysis were as follows:

	Specific gravity	Compression strength	Toughness
Degrees of Freedom:...	20	20	20
Actual "t".....	4.59	8.40	6.71
5 percent "t".....	2.09	2.09	2.09
1 percent "t".....	2.84	2.84	2.84

For each group of test values put to the "t" test the results showed actual "t" to be greater than either five or one percent "t", and the conclusion may be drawn that in all probability the variations in these properties be-

Table 2.

Results of Specific Gravity Determinations and Mechanical Tests on Populus Species

Species	Log No.	Specific Gravity		Max. Compression Strength Parallel to Grain				Toughness			
				Number Samples Averaged		Averaged Values (psi)		Number Samples Averaged		Averaged Values (in. lbs.)	
		Sap wood	Heart wood	Sap wood	Heart wood	Sap wood	Heart wood	Sap wood	Heart wood	Sap wood	Heart wood
Balsam Poplar	1	.327	.302	12	12	1736	1613	12	12	120	55
	2	.323	.306	12	12	1871	1506	12	12	102	51
	3	.341	.314	25	25	1795	1356	24	24	142	57
Av.		.330	.307			1801	1492			121	54
Cottonwood	1	.367	.361	25	25	1978	1266	22	22	313	237
	2	.356	.337	25	25	2154	1335	25	25	338	218
Av.		.361	.349			2066	1300			325	227
Largetooth Aspen	1	.413	.353	25	25	2927	2387	25	20	105	57
	2	.400	.374	25	20	2862	1843	21	14	100	93
Av.		.407	.363			2894	2115			102	75

tween the aspen heartwood and sapwood are real and inherent in the wood itself and are not a result of sampling error or chance.

The corresponding data for other species tested were not analyzed statistically but from inspection it appears that the differences observed were significant.

Increment Growth and Specific Gravity

Growth ring counts indicated that generally there were more growth rings per inch in the sapwood than in the heartwood of all species. From this it may be concluded that there was a retardation in radial growth as the trees grew older. According to Paul (11), in diffuse-porous woods such a continued retardation of increment growth will result in more porous rings and consequently wood of lower specific gravity. Therefore, from a growth standpoint the sapwood should be expected to be lower in specific gravity than the heartwood. Experimental results, however, showed the opposite to be true. Thus, the higher specific gravity in the sapwood than in the heartwood is contrary to what would be expected if the growth rate were the controlling factor of specific gravity. Some other influence must have been in operation either in decreasing the heartwood specific gravity relative to that of the sapwood or in increasing the specific gravity of the sapwood relative to the heartwood.

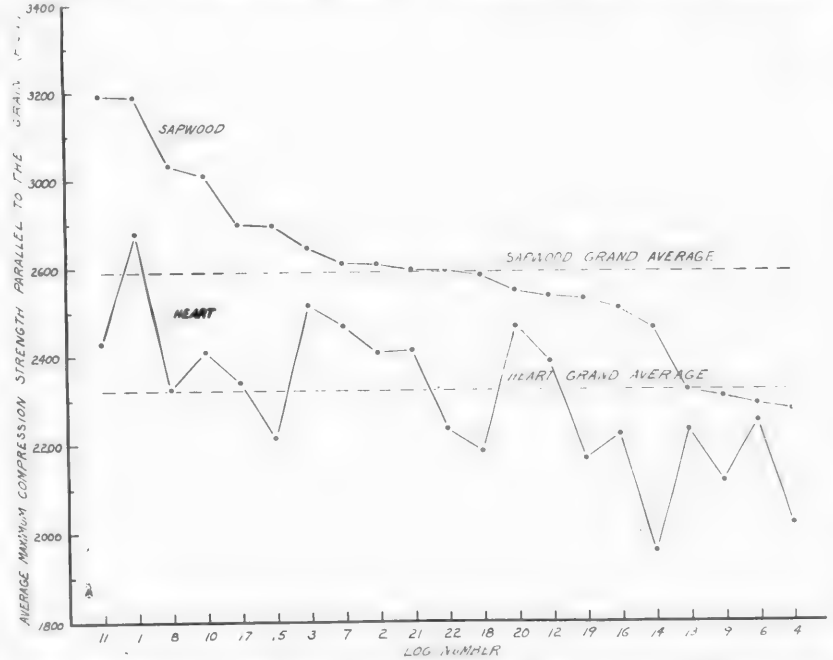

Figure 2.—Comparative compressive strengths of the heart- and sapwood of 22 aspen logs.

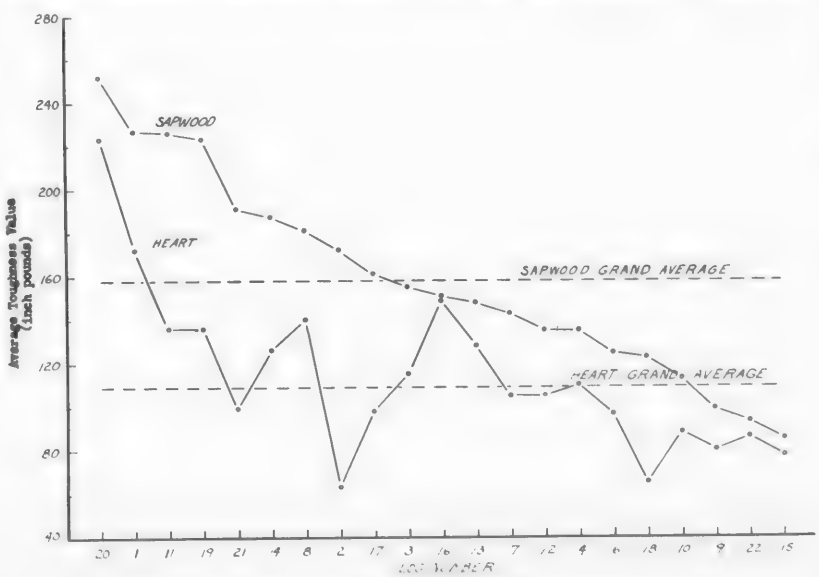

Figure 3.—The comparative toughess of aspen heart- and sapwood.

Inasmuch as the latter seems highly improbable, if not impossible, some explanation for the decrease in heartwood specific gravity is in order. Incipient decay by wood-rotting fungi is one possible explanation. Decay by fungi, however, can be discounted on the basis of the lack of actual isolation of such organisms from the wood in all except the one log in which decay was obvious. In view of the data collected, the only other possible explanation for the decrease in specific gravity in the heartwood is that the common bacterial inhabitants of species of *Populus* are responsible. While this explanation is based entirely upon circumstantial evidence, and more positive proof from inoculation studies is needed, the results of the studies certainly indicate that bacteria are responsible for the degradation of heartwood and "wetwood" of the species studied.

Compression Strength

The compression strength of wood is generally recognized to vary directly with the first power of its specific gravity (1). Within a given species, therefore, the relationship between the compression strength and the specific gravity can be represented by the equation ($f = a + pG$), which is the equation of a straight line not going through the origin in which (f) is the maximum compression strength, (a) and (p) are constants and (G) is the specific gravity of the piece of wood.

In order to determine whether this type of general equation could be used to represent the aspen data obtained in the present investigation, correlation coefficients were calculated individually for heartwood and sapwood for compression strength as a function of specific gravity. For this analysis the average maximum compression value and the average specific gravity for each zone of each log were used. The following results were obtained:

	Sapwood	Heartwood
No. of Aspen logs	21	22
Actual "r"	.531	.577
5 percent "r"	.433	.423
1 percent "r"	.549	.537

The sapwood correlation coefficient is greater than that at the five percent level but smaller than that at the one percent level, indicating that a fairly high degree of correlation exists between the two. Actual "r" for the heartwood is greater than either the five or one percent "r" and the relationship in the heartwood is therefore considered to represent a high degree of correlation. Thus, the general straight line equation ($f = a + pG$) can be used to represent the relationship between the maximum compression strength of each zone and the specific gravity for the corresponding

zone for the results of the tests on aspen. By calculating the constants (p) and (a) for each zone, the following equations were obtained:

For the sapwood zone: $f = 1093.5 - 3773.6G$
For the heartwood zone: $f = 756.7 - 4149.3G$
in which f = unit compression strength in psi.
G = specific gravity of the zone in question.

These two equations are represented graphically in Figure 4. In calculating the significance of the difference by the "t" test between the two curves in order to determine whether the curves actually represented similar relationships in different populations or merely different samples of the same population, the following was obtained:

Degrees of Freedom	= 20
Actual "t"	= 5.61
5 percent "t"	= 2.09
1 percent "t"	= 2.84

From the test it is evident that the difference between the two curves is highly significant and that therefore the curves actually represent different populations.

This relationship is further evidence attesting to the influence which some outside agent has had on the heartwood of the aspen. If the only difference between the heartwood and sapwood were specific gravity, the average compression strength values for the two zones would be different, but the strength relationship between zones could be represented by a single curve of the compression strength as a function of specific gravity. The results would strongly indicate that some agent, such as bacteria, has been at work in the wood and selectively reduced the strength-giving constituents of the heartwood so that the net effect was to reduce the specific gravity by a given percentage but to reduce the compression strength by a greater percentage. If this were not the case, the relation of compression strength to specific gravity in heartwood and sapwood could be represented by one equation, which has been shown to be impossible.

This same evidence can also be seen in a different form in Table 3. Since compression strength varies directly as the first power of specific gravity, a five percent decrease in specific gravity would be expected to effect a similar reduction in compression strength. However, the 5.3 percent reduction in specific gravity in the heartwood was accompanied by an 11.5 percent reduction in compression strength.

TABLE 3—*Summarized Results of Specific Gravity, Compression and Toughness Strength Tests on the Aspen Tested.*

Species	Sapwood	Heartwood	Average Difference	Percentage Difference (based on heartwood
Aspen				
Av. Sp. Gr.	.397	.377	.020	5.3
Av. Comp. Strength (psi.)	2592	2321	271	11.5
Av. Tough. Value (in. lbs.)	158.0	113.7	44.3	32.4

Toughness Strength

Toughness strength or strength in resistance to forces of short duration is generally recognized to vary with a power of the specific gravity which is greater than one (1). Such relationships can be represented by a parabolic equation of the type ($f = pG^n$) where (f) is the strength value, (G) is the specific gravity and (p) and (n) are constants which is the equation of the parabola of the nth degree passing through the origin. In order to simplify the calculation of the constants for the equations for each zone, the equation was changed into its logarithmic form ($\log f = \log p + n \log G$), which is the general equation for a straight line having a slope equal to (n) and crossing the y axis at a value equal to log (p). The correlation coefficients for aspen sapwood and heartwood toughness as a function of their corresponding specific gravities were computed and the results were as follows:

	Sapwood	Heartwood
No. of Logs	21	22
Actual "r"	.581	.622
5 percent "r"	.433	.423
1 percent "r"	.549	.537

Both actual correlation coefficients are greater than either the five or one percent values for the number of samples tested, indicating that the correlation is highly significant. The straight line form of the equations were derived and transformed into the parabolic equations which are:

For the sapwood $f = 1416\ G^{2.411}$
For the heartwood $f = 1292\ G^{2.519}$
in which (f) is toughness in inch pounds and (G) is specific gravity

These equations are shown graphically in Figure 5. Again it was deemed desirable to know the statistical probability of the two curves representing different populations or different samples of the same population. The "t" test of significance was run on the difference between the curves and the following results were obtained:

Degrees of Freedom	= 20
Actual "t"	= 6.55
5 percent "t"	= 2.09
1 percent "t"	= 2.84

Statistically, therefore, it must be concluded that the difference in the curves is highly significant and they must be considered to represent different relationships which cannot be represented by a single equation.

Here again, if in the aspen logs the specific gravity fluctuations between heartwood and sapwood represented merely a normal variation in growth we would expect the toughness and

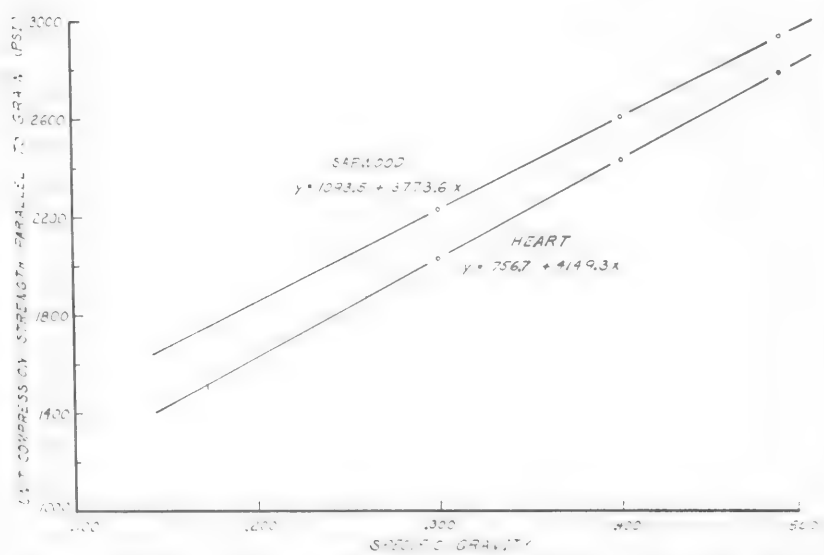

Figure 4.—Regression equation for aspen heartwood and sapwood unit compression strength parallel to the grain as a function of specific gravity.

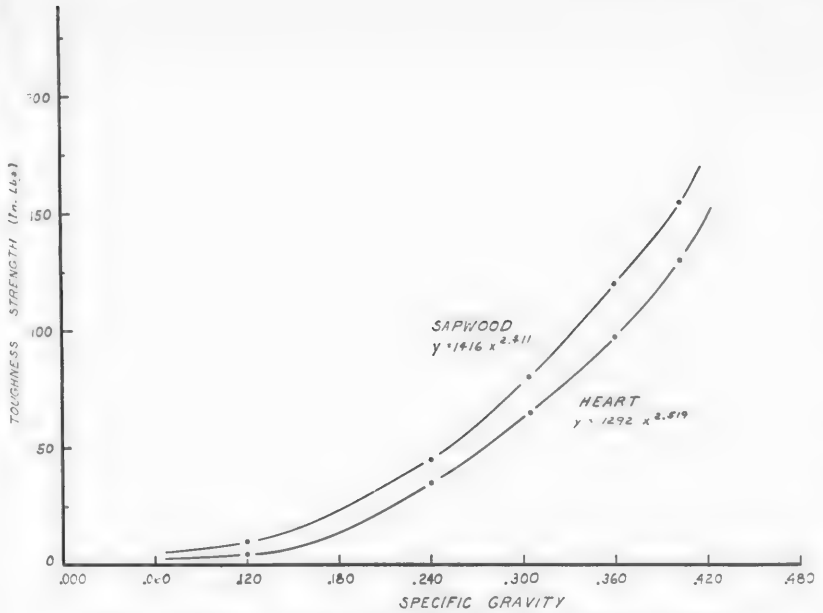

Figure 5.—Regression equation for aspen heartwood and sapwood toughness strength as a function of specific gravity.

specific gravity data for the heartwood to fill in around the lower part of the normal curve for sapwood. The "t" test, however, has shown us that this is not the case and that a separate curve is needed to represent the heartwood relationship. This is further evidence to the effect that some selective action has reduced the strength of the heartwood to a greater degree than would be expected for the corresponding specific gravity reduction.

The characteristic brash type of failure of toughness samples found in the heartwood of the species tested presents a situation very similar to that which Dadswell and Langlands (7) describe for species of *Eucalyptus*. In both cases the central portion of the tree is brittle and of comparatively low impact strength. Both contain central regions which tend to collapse under drying conditions. However, their observation of a large percentage of broken fibers among those observed upon maceration of the central "brittle heart" could not be duplicated in the species tested by the author. Dadswell and Langlands suggest that "brittle heart" in the wood they tested may have resulted from the action of wood rotters, but they show no evidence that wood rotters were present in the wood under consideration.

Summary

Bacteria, possibly of a few closely related species, are commonly associated with the heartwood of aspen, balsam poplar, and cottonwood.

The specific gravity of the heartwood has been reduced and it appears highly probable that this has resulted from the action of the bacteria so abundantly present.

The heartwood is weaker in compression strength parallel to the grain than is the normal sapwood, to an extent which indicates that there has been a rather serious degrading action on the wood.

The heartwood is also considerably weaker in toughness, again to an extent that suggests the probability that some outside agent has affected the wood.

The general conclusion which may be drawn from this study is that in the species of *Populus* investigated it appears that bacteria are present and active in the heartwood and that they in some way affect the wood, probably causing the common discoloration and the reduction in compression and toughness strength and specific gravity which accompany the discoloration.

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Figure 6. — Aspen toughness specimens showing typical failures. Four sapwood specimens below with splintery-type failure. Four heartwood specimens above with brashy failures. Specimens cut from the heart- and sapwood of the same log. No decay was present but bacteria were abundant in the heartwood.

Hardboard in U. S.—From page 6

Future Possibilities

The future of hardboard seems established. The extent to which it will grow will depend to a considerable extent on such factors as the extent to which new uses can be developed, the amount buyer confidence can be built up, the continuation of production, freight, and merchandizing costs that will keep hardboards competitive with other materials, and the improvement of product to meet special requirements.

The size of operation that will support a hardboard mill is much smaller than that needed for pulping for paper production, as are water requirements. From observations made, it appears that hardboard mills will be built in multiples of about 70-ton-per-day capacity. A 70-ton mill is about the size needed to keep a 20-opening 4- by 16-foot hot press operating at capacity with the press cycles required for conventional wet-felted boards. With longer or shorter press cycles, capacity would be adjusted proportionately. That so many species are currently being used to make hardboards illustrates the versatility and the possibilities in hardboard of a more complete utilization of total growth of timber.

It seems to be the consensus of many of the people working in this phase of forest products that a substantial part of the future lies, not in flat sheets, but in molded shapes. Another possibility, which as yet has been only scratched, is in the manufacture of fiberboards in the intermediate densities (specific gravity 0.4 to 0.8) for such specialty uses as core stock for veneered furniture. If the demand is there, fiberboards can be manufactured in lower densities than those of the present hardboards, but using the same basic manufacturing procedures except that pressing will be done at lower pressures. The present edge-glued lumber cores are not entirely satisfactory.

Time only can tell where the final level of use of hardboards will be. This relatively new industry requires the continuing guidance and imagination of all connected with it to help it attain the status possible for it.

Rough Mill—From page 34

Last, but not least, in our list of predominate factors in the operation of an efficient rough mill is the continuous education and training of personnel. The dollar volume of material handled by cut-off saw and rip-saw operators is often overlooked by management, and I would venture to say that in 95 percent of the cases, the operators do not have the least idea of the dollar value of the material they are handling daily. Therefore, it is very necessary to have periodic training sessions to impress upon the operators the value of the material and to give them instructions on how to properly cut a board to obtain the greatest yield. A good plan is to call a meeting with the cut-off saw and rip-saw operators and, in addition to general discussions, have them mark a board with a crayon indicating the cuts they would normally make with their machines. This always creates great interest and a competitive spirit among the operators for the best yield. It is recommended that it be done every six months to refresh and renew the operators' interest.

Qualified maintenance men are necessary for the setting of facers and planers to cut out the biting of the ends of the lumber and assure a good feeding process. It takes a man with "know-how" to make the necessary accurate adjustments, and it also takes a man with "know-how" to do the grinding on the planer heads. In other words, trained personnel is important.

Furniture—From page 48

factory to develop pride in the firm's achievements. Wages and standards of living in the two countries are compared.

Sales Methods

A section is included on the furniture markets or exhibitions through which about 65 percent of all sales are made. Market research and methods of advertising are also dealt with. A considerable effort is made to establish contact with the consumers as well as with the retailers.

Trade Associations

The work of the Trade Associations includes collecting statistics and compiling trading results which are published with a minimum of delay so that each firm can compare its own results with that of the industry as a whole.

Conclusions

The Team pay tribute to the value of their visit as a means of exchanging information and ideas which should be of advantage to both countries. They then make specific recommendations to each group within the British industry as they consider that the results of this visit are of importance to every employee as well as to management. These recommendations may be summed up as a plea for a more open-minded approach on the part of all concerned to the use of new ideas and methods, whatever their source, and a ruthless elimination of unnecessary operations which add to the cost but not to the value of a product. For this purpose a study of materials handling engineering would be of value.

Overlays—From page 53

The natural color of the overlay is a light gray. Although it is presently being dyed to approximately match the color of fir, it can be produced in various colors. Work is underway, with interesting results, on printing wood grain designs on the sheet.

A panel prepared with an overlay of this type has a high degree of check resistance. By choosing proper conditions during manufacture, a sheet of high tensile strength can be made, which, when pressed on single veneers, yields a panel structure of increased strength. This is of interest when considering veneers infected with white pocket rot, since the strength of the veneer itself is of less importance than the outer skins. An appreciable amount of rot can be tolerated without affecting the flexural strength of the finished panel markedly.

Status of the Overlay Development

To summarize the current status of plywood overlay, development and use, it can be said that the production of these new materials is increasing and will continue to increase significantly. The trends in raw material availability will, sooner or later, force consideration of new surfacing materials. Our organization intends to continue intensive research in this field, and is desirous of cooperating with the Douglas-fir plywood industry in developing the types of overlay surfacing required in keeping with future conditions. It is felt that the development described above, of a more economical low density overlay will be the answer to the largest share of masking overlay applications. The sheet is versatile in that it can be used as is as a smooth painting surface, or subjected to a post-forming embossing operation to give a variety of decorative effects.

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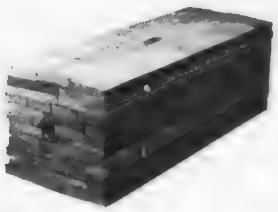

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Modified Woods—From page 56

treated materials. Compreg will find many uses and for specialized purposes has already proven very useful, but no great increase in its use appears imminent except for expansion of present types of uses.

Question (Don Horner)—Is the fire hardening of ancients same as staybwood?

Locke—The process of dimensionally stabilizing wood by heating (staybwood) is probably similar to the fire-hardening process used by the early peoples. The stabilization of wood by heating is accompanied by a considerable loss in toughness of the wood. The high content of silica in bamboo may be the reason for the success in hardening bamboo.

Question (T. D. Perry)—The dimensional stabilization of wood is the object of the treatment. Can you treat the surface only?

Locke—A satisfactory surface stabilization can be obtained by the acetylation method. In acetylation the treating chemicals are in the vapor phase and as a result, the process is adaptable to the surface treatment. Exposure tests of surface acetylated wood have produced excellent results, especially in improving the weathering and painting characteristics. Ordinarily resin impregnation of wood is accomplished by treating veneer and laminating. The process requires too long a time for the penetration of the resin into the internal structure of the thick pieces of wood and for the subsequent removal of the water which was the carrier of the resin. A satisfactory product for plywood faces has been made from many species of wood which have been impregnated with a resin, but only single veneers were treated. However, again except for special cases, the resin-impregnated material was too expensive.

Question—Would surface treatment be applicable for the densification of contour and flat edges?

Locke—When wood is impregnated with a resin, the wood is swollen and most of this swollen condition is maintained. When this is applied only to the surface, checking and warping generally occurs. When densifying on contour, it would be better to control the moisture content and to produce a form of staypak. This staybak type of contoured edge is satisfactory unless subjected to extreme changes in moisture or high humidities, in which case considerable recovery of compression may result and possibly wood failure may occur at the juncture between the compressed wood and the uncompressed wood. The most satisfactory method we know of now would be to produce a resin-impregnated compressed veneer, form it to shape, glue it on the surface of a normal machined wood part similar to the process developed by the Timber Engineering Company.

Question (Hamilton of Formica)—What is the effect of the resin and compression on the stiffness or flexural strength of the wood?

Locke—Stiffness or flexural strength properties of wood increase as the degree of compression or density of the wood increases. Resin impregnation generally improves the stiffness of wood or wood laminates across the grain.

Prefab—From page 12

indicating who built it. The large builders and prefabricators, on the other hand, having large sums of money tied up in expensive construction machinery and plants must establish a name and maintain a good reputation.

At the present time wood or wood in its various manufactured forms such as plywood or fiber board, will continue to maintain its popularity in the prefabrication industry. Wood fiber products, in time, will be developed into more plastic types of material with more favorable structural and other fabricating properties. With a reduction in price of such plastic wood fiber products or reduction in supply of wood itself, plastic-like materials will grow even more popular with the prefabricator and building industry in general.

In our construction, we have found production advantages in the use of the truss over the normal ceiling joist and rafter construction. Such roof construction can not only be more quickly erected at site, but also can be readily jig-assembled by semi-skilled labor. It is not too bulky to ship or handle and since it undergoes practically no change of shape after fabrication it serves as a means of lining up exterior walls and leveling of ceiling surfaces. Most prefabricators insulate the ceilings of their houses. Usually, as in our case, in order to prevent condensation in attic space and to avoid overheating that space in summer, the roof is provided with louvered openings in the roof and soffit vents for adequate ventilation.

With a few exceptions, the prefabricators have for various reasons favored the hot air system for heating their homes. These reasons are in part due to convenience, cheapness of installation and convenience in operation. Oil- or gas-fired systems are in the vast majority. In our case, furnaces and hot water heaters—usually gas or electric are optional features.

Though our country is the wealthiest and most industrialized in the world, we still have millions of citizens without adequate housing. Our present inflation has made it difficult to maintain the price of homes at the former levels. Our 50-cent dollar has forced the building industry to reduce the size of its product and generally to move to cheaper land. The Cape Cod type of home, for example, with two floors which we produced and whose total cost including land was approximately $10,000 immediately after World War II, would now cost complete with lot more than $15,000. At this figure it would be beyond the reach of the lower income group. Therefore, we are not manufacturing such a home today.

Formation of the PHMI

In 1942, the prefabricators of homes formed the Prefabricated Home Manufacturers' Association to disseminate information, establish and maintain and improve industry standards, study distribution problems, improve manufacturing methods, make cost and accounting studies and serve as a medium for the exchange of ideas. In September 1943 PHMA changed its name to Prefabricated Home Manufacturers' Institute. In 1944, at the insistance of said Institute, a proposed commercial standard for Prefabricated Homes was written, and accepted by the Trade. In 1945, this standard was first published as Commercial Standard, CS-125-45, and made available by the Department of Commerce, through the Government printing office at Washington, D.C.

This Standard is more stringent than most performance codes. Through this Standard, the Harnischfeger Corporation, and all the other members of Prefabricated Home Manufacturers' Institute, assure the prospective home buyers of the very best in low cost quality homes.

Decay Test—From page 28

since the electrical testing technique does not seem to be sufficiently sensitive to detect such small amounts of decay. Despite this lack of sensitivity, the electrical testing of wood might prove advantageous where there was need for a non-destructive test.

Summary

Previously weighed pieces of the sapwood of loblolly pine and red gum were subjected to decay by pure cultures of white and brown rot organisms. At 2-week intervals up to 14 weeks of decay, samples were removed from the decay chambers, tested electrically at 5 megacycles with a Q-meter, weighed, measured, oven-dried and reweighed. The moisture content at time of testing, specific gravity, and percent weight-loss due to decay were calculated, and their relations to dielectric constant and to conductivity were studied by means of multiple and partial regression analyses. Moisture content had the greatest effect on the electrical properties, but in addition there was a highly significant partial regression of the conductivity of the wood on the percent weight-loss due to decay. There was also a highly significant partial regression of the dielectric constant of the wood on its specific gravity.

In the range of moisture contents studied the difference between a conductivity moisture meter reading and a dielectric constant moisture meter reading seemed to be a fairly good non-destructive test for decay, the former being consistently higher than the latter for decayed pieces of wood.

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Burning—From page 32

on the grooved surface. It would, therefore, be logical to assume that in the latter case the glue was forced into the groove either when spread or when edge pressure was applied which resulted in a more uniform glue film. In contrast, the air trapped in the groove when the spread surface was placed against it could easily give rise to an air bubble which would affect the value of R_g in a manner similar to that of a ridge.

The fact that the sawn joints behaved similarly to the smoothly jointed surfaces was somewhat surprising since slight ridges and grooves occurred along these surfaces due to the action of the saw teeth. However, these irregularities were at an angle of approximately 45 degrees to the horizontal which, from an electrical standpoint, meant that they did not form regions of high dielectric stress since the r.f. current could easily follow such paths.

Also in keeping with theory is the fact that the minimum voltage gradient for curing is lowered with an increase in glue conductivity. This is based upon the relationship for power in a parallel circuit:

$$P_g = \frac{E^2}{R_g} \text{ watts} \qquad (4)$$

where P_g is the r.f. power dissipated as heat in the glue lines, E is the impressed r.f. voltage and R_g is the effective parallel resistance of the glue lines. An increase in conductivity means a decrease in R_g, consequently, for a constant power input the value of the impressed voltage is reduced.

Figure 6A indicates that in the case of basswood the effect of either a ridge or a groove is to lower the threshold voltage gradient for burning for the lower conductivity mix. The concomitant effects of glue conductivity and r.f. voltage apparently result in burning at a lower gradient regardless of the type of surface irregularity in the case of the higher conductivity mix. On the other hand, in maple only a ridged surface resulted in a lower burning voltage for either of the mixes, although an increase in conductivity lowered the burning gradient as well as the curing voltage for the several surfaces under test. An increase in either edge pressure or heating time in the basswood tests resulted in a more intense burn but did not lower the r.f. burning threshold voltage. Similar effects were noted for the maple.

Conclusions

The erratic nature and occurrence of r.f. burning makes the determination of its causative factors rather difficult. The levels of the r.f. voltage which appear to be thresholds of burning can only be considered approximations since identical results did not always obtain when tests were replicated. The effects of surface discontinuities, however, were more straightforward. In general, it is possible to conclude that—

1. R.f. burning is a dielectric phenomenon associated with the establishment of regions of high resistance in a glue joint due to irregularities on the wood surfaces.
2. The factors which may affect the frequency of burning are:
   a. R.f. voltage gradient.
   b. Non-uniformity of the wood surfaces due to anatomy or machining characteristics.
   c. R.f. conductivity of the glue.
3. The factors which may affect the intensity of burning are:
   a. Composition and amount of filler in the glue.
   b. Glue spread.
   c. Edge pressure.
   d. Duration of heating period.

Acknowledgment

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Abstracts

The preparation of abstracts from world literature in many languages is so highly specialized and costly that the Forest Products Research Society has no abstracting service of its own. For the abstracts in this issue of the JOURNAL the Society is indebted to the respective abstract journals indicated, from which they have been selected with the kind permission of the editors. Readers wishing information in addition to that given in these abstracts should consult the original articles referred to. Copies or additional information can not be supplied by FPRS or the abstract journal. The journals from which abstracts are published in this issue are as follows:

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General

Desch, H. E. Manual of commercial timbers. Volume 1. The Author, Woodman's Folly, Crockham Hill, nr. Edenbridge, Kent. 1951. Price £1. 1s. Od.

Notes on the nomenclature, structure, properties, uses and supply of 60 species, with an anatomical drawing of each. The work is issued in loose-leaf form, and supplementary sheets covering 10 or 20 timbers will be issued periodically. Descriptions will be revised as additional information is obtained. Specimens of the timbers described are available to supplement the text. (For. Prod. Util. Abs.)

Pereira, J. Aranha, and Mainieri, C. Madeiras do Brasil. Sua caracterizaçâo, usos comuns e índices qualificativos físicos e mecânicos. [Brazilian timbers: description, common uses, and physical and mechanical properties.] An. bras. Econ. flor., Inst. nac. Pinho 2(2), 1949 (283–351). [Port.] (For. Prod. Util. Abs.)

Madeiras brasileiras de exportaçâo. [Export timbers of Brazil.] An. bras. Econ. flor., Inst. nac. Pinho 2(2), 1949 (43–50). [Port. e.]

Vernacular names, with synonyms, listed alphabetically, and scientific names and exporting states. (For. Prod. Util. Abs.)

Bublitz, W. Die wichtigsten Holzarten der Mangrovewälder Kolumbiens. [The most important timbers of Colombia's mangrove forests.] Z. Weltforstw. 14(5), 1951 (157–8). [G.]

Describes the tree and the wood and gives vernacular names, properties and uses of *Rhizophora mangle, R. racemosa, Avicennia nitida* and *Conocarpus erectus*. For. Prod. Util. Abt.)

Bublitz, W. Die wichtigsten Holzarten des Monsunwaldes Kolumbiens. [The most important species of Colombia's monsoon forests.] Z. Weltforstwirt. 15(1), 1952 (34–5). [G.]

Describes the timber and its properties and uses, with brief notes on the tree and its distribution, for 10 common species. (For. Prod. Util. Abs.)

Lamb, G. Foreign woods. Wood, Chicago 57(2), 1952 (78–9). P.R.

Cojoba, *(Cojoba arborea);* Black Kateralli *(Eschweilera sagotiana);* Frijojillo *(Pseudosamanea guachapele);* and Vaco *(Magnolia sororum).* (For. Prod. Util. Abs.)

Wood and Its Properties

Wright, R. H., and Hayward, A. M. Kinetics of the thermal decomposition of wood. Canad. J. Technol. 29(12), 1951 (503–10). P.R.

The rate of decomposition of dry Western Red Cedar and Western Hemlock when introduced suddenly into an atmosphere of N at 500, 700, and 900° C. has been studied. For cubical pieces the reaction is approximately of the one-half order; for disks it is of zero order. For cubes the rate constant is directly proportional to the specific surface and to the temperature, and the proportionality constants are the same for both species of wood. Authors' summary. (For. Prod. Util. Abs.)

Fons. W. L. Heating and ignition of small wood cylinders. Industr. Engng. Chem. 42(10), 1950 (2–30). 12 refs. P.R.

Cylinders of Ponderosa Pine from 3/32 to 3/8 in. in diameter and of known moisture content (m.c.) were tested in a furnace above the ignition temperature of the wood. The temperatures at different radii of each specimen were recorded at intervals, and the time until the first appearance of flame was measured. M.c. lengthened ignition time more than can be explained by the rise in specific heat due to moisture. Up to 1300° F. ignition time increased as size of the specimens increased; above 1300° the size had no effect on ignition time. It was found that flames may appear in a mass of material if some parts of it are heated to not less than 800°. If some material is reduced to charcoal, it will be rekindled by a temperature of 450°. It was found that the surface ignition temperature of wood under conditions of rapid heating was nearer to 650° than to 550° as usually quoted. (For. Prod. Util. Abs.)

Mitchell, N. D. New light on self-ignition. Quart. nat. Fire Prot. Ass., Boston 45(2), 1951 (165–72). 4 refs. D.S.I.R.

Tests with wood-fibre insulating boards, felted purified cotton linters, coal, and hay, showed that spontaneous heating in appreciable amounts was observable at relatively low ambient temperature. The larger the volume involved, the lower the temperature required to initiate perceptible self-heating. Likewise, the temperatures required to cause self-ignition of the larger volumes of material were decidedly lower than those required for the self-ignition of the smaller ones. Whereas ambient temperature of 603° F. was required to cause the ignition of a 1/8-in. cube of wood fibreboard, a specimen 22 in. thick requires only 228° to ignite it through spontaneous heating. The self-heating of a 12-in. specimen at 147° was appreciable. In fact, the self-heating was accelerated to ignition when the ambient temperature was raised to prevent undue loss of heat from the reaction so started. Author's summary. (For. Prod. Util. Abs.)

Perkitny, T. Badania nad cisnieniem pecznienia drewna. [Investigations on the swelling pressure of wood.] Prace Inst. Bad. Lesn. No. 64, 1951. pp. 116. 45 refs. [Pol.]

Presents the results of an investigation on the swelling pressure of timber with various degrees of initial moisture content, the effect of pressure on the swelling of timber, and the compressibility of timber swollen under pressure. The swelling pressure measured was that which had to be applied to the test piece during wetting in order to maintain at the pre-wetting level one dimension of the test piece, parallel to the pressure measured. The swelling-pressure/wetting-time curve rises first steeply then more gently and, after having reached a maximum value, usually falls. It begins to fall while both moisture content and degree of free swelling are still increasing vigorously. The swelling pressure corresponding to a free swelling of 1% varies from 0.9 kg./sq. cm. for Poplar to 3.7 kg./sq. cm. for Ash. The mechanical pressure that must be applied to a swollen test piece to restore the absolute-dry-state dimensions is, for all species tested, several times greater than the swelling pressure proper. While it is true that tangential swelling is greater than radial, the swelling pressure is usually greater in radial than in tangential direction. Swelling pressure exerted by plywood parallel to the layers is only ca. 7% of that exerted by a similar thickness of solid wood, while swelling pressure perpendicular to the plies is nearly the same as that for solid wood. The swelling pressure exerted by wet timber is the less, the higher its initial moisture content. Wet timber subjected to swelling under pressure is less compressible than wet timber swollen without pressure. Wet timber swollen under pressure is up to a certain boundary stress less, and above this stress more, compressible than absolutely dry timber. (For. Prod. Util Abs.)

Keylwerth, R. Die anisotrope Elastizität des Holzes und der Lagenhölzer [Anisotropic elasticity of wood and laminated wood.] VDI–Forschungsheft, Düsseldorf No. 430, 1951. pp. 40. 47 refs. [G.] X.

Includes sections on: wood as a rhombic crystalline material; simple stress cases with anisotropic elasticity; determination of constants for wood; elasticity of laminated woods. (For. Prod. Util. Abs.)

Mack, J. J., and Cooper, K. L. Projects T.M. 9–14 and 9–15. Progress report No. 1. Mechanical properties of plantation-grown Slash and Loblolly Pines. Division of Forest Products, Commonwealth Scientific and Industrial Research Organization, Melbourne. 1951. pp. 5 + 1 photo, 6 tbls. 13 refs. P.R.

Tabulated data of various mechanical properties of green and air-dry specimens of both species. (For. Prod. Util. Abs.)

Kudzin, S. F., and Nord, F. F. Investigations on lignin and lignification. VII. Characterization of enzymatically liberated hardwood lignins. J. Amer. chem. Soc. 73(10), 1951 (4619–22). 3 refs. O.R.S.

The enzymatically-liberated lignins of Oak, Birch and Maple obtained by alcoholic extraction after 10 months' decay by *Daedalus quercina* were compared with the native lignin fractions of the same species. The native and enzymatically-liberated lignins of each species were identical in all respects studied. A nomenclature based on the presence of the guiacyl and syringyl grouping in lignins is proposed. From authors' summary. (For. Prod. Util. Abs.)

Iroko (Chlorophora excelsa). Bois et forêts des Tropiques, France, No. 21, January–February 1952, pp. 27–30, illus. (in French).

The wood of iroko is a pale greenish yellow when cut, darkening on ex-

(Continued on page 74)

Recent Publications

Presented below are brief descriptions of recent publications that have been issued by various research and educational institutions. Since none of these publications are available from the Forest Products Research Society inquiries should be directed to the organization issuing the various reports.

Wood Waste Utilization in Canada. J. H. Jenkins, 1952. Forestry Branch Bulletin No. 103, Canada Department of Resources and Development. J. H. Jenkins, Chief of the Forest Products Laboratories Division, summarizes realistically the practical advances that have been made by forest products industries in the timber provinces.

Wood Flour Production in Canada. E. H. Buckley, Canada Lumberman, May 1952. General exposition for those who may be wondering about the possibilities of wood flour production. Nine references.

Bark Extracts in Adhesives. H. MacLean and J. A. F. Gardner, Pulp and Paper Magazine of Canada, August 1952. Because of its content of phenolic materials, attention is drawn to the possibility of utilizing in the manufacture of adhesives some of the extractive content of the bark from pulpwood and sawlogs. Results are presented of initial tests on the usefulness of Tannin extracts, prepared by simple hot water extraction of sea-water floated western hemlock bark. They show that western hemlock tannin reacts rapidly with formaldehyde and that it is compatible with phenol-formaldehyde resins. The tannin extract was substituted for up to seventy-five percent of the phenol-formaldehyde resin in a weatherproof plywood adhesive without impairing the strength and durability characteristics. The authors are on the staff of the Vancouver Laboratory of the Forest Products Laboratories Division, Forestry Branch, Department of Resources and Development, Canada.

Microbiological Degradation of Lignocellulosic Material. D. W. Stranks, Pulp and Paper Magazine of Canada, 1952 Convention issue. Since cattle are known to effectively digest cellulosic materials the possibility has been explored of using some of the rumen organisms for the fermentation of wood waste. Early difficulties in culturing the organisms are reported.

Brown Stain in Pine Sapwood Caused by *Cytospora spp.* Clara W. Fritz, Ottawa Laboratory, Canada, 1952. Canadian Journal of Botany, 30: 349–359. It has been shown that a species of *Cytospora* causes chocolate brown stain in the sapwood of red pine and jack pine poles held under unfavorable storage conditions. The fungus develops in the ray parenchyma, stains the cell walls, but penetrates the walls only through the pits. Mechanical tests carried out on sticks stained in pure culture showed that the effect of the fungus on bending strength and toughness is negligible.

Third Biennial Report of the Forest Products Commission (October 1, 1950–September 30, 1952) State of Washington Institute of Forest Products, Department of Conservation and Development. An excellent resume of the Institutes accomplishments with summaries of the publications that have been issued.

Tannin from Waste Bark. Northeastern Wood Utilization Council Bulletin No. 39. September 1952. $2.50. Includes the following articles—"The Tannin Material Situation" by W. E. Hillis (Australia), "The Tannin Industry in New England" by Kenneth E. Bell, "Operation of a Tannin Extract Plant" by Edwin S. Flinn, "Potential Tannin Supplies from Domestic Barks" by Jerome S. Rogers, and "Methods of Bark Separation" by G. W. Jarman. In the last-named section air flotation, thermo-pressure, and cyclone methods are described.

(Continued on page 75)

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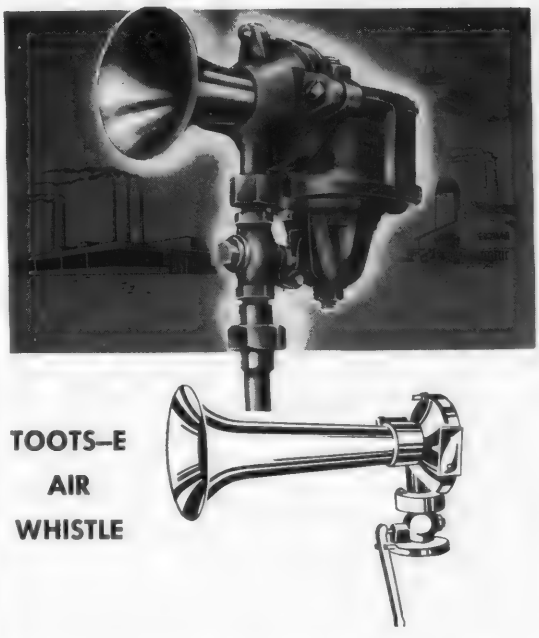

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posure to a yellowish brown, some specimens deepening to chocolate. The sapwood, which is unusable, is a pale yellow. In texture the wood is coarse with the pores easily visible. The grain is usually irregular giving a moire effect; regular cross-grain sometimes produces a ribbon figure. The wood is slightly oily to the touch. It is fairly hard and heavy and air- or kiln-dries without difficulty.

Sawing can usually be carried out easily but some specimens contain secrétions which blunt blades rapidly. Machining is fairly easy except for wood having marked crossgrain. The wood takes a good polish and can be varnished but requires filling. Paints based on linseed oil may be incompatible with the oil in the wood and may not adhere. This difficulty can be overcome by first coating the wood with a varnish based on alcohol. Alternatively paints without linseed oil can be used. (Tech. Bul. F.D.C.)

Physical and chemical aspects of wood structure in relation to use. D. J. Roach. Timber News, Vol. 60, Nos. 2151–4, January–April 1952, pp. 27–9, 81–3, 134–6, 178–9.

One of the chief factors affecting the strength of wood is its specific gravity which, in turn, depends on the amount and composition of cell wall substance, the thickness of the cell walls, the numbers of cells per unit volume and the presence of deposits and infiltrates. A defect sometimes found in hardwoods is tension wood which is formed in the tree on the upper sides of leaning stems and branches. Within a species, strength is thought to increase as cell length increases.

In general the thermal conductivity of a wood is related to the density, while the acoustic properties depend on several factors including density, elasticity and uniformity of texture. Shrinkage depends on the composition and physical structure of the cell walls, the mineral and organic extractives and the deposits present. The lignin content of wood has very little effect on bending properties and modulus of elasticity and only a slight effect on compression. The cellulose content has a more marked effect on these three properties. Resins, gums, and mineral deposits influence mainly the abrasion resistance and surface hardness although the presence of certain soluble salts may affect shrinkage and hygroscopicity. Amongst the chemicals present in wood composition are hemicellulose and penstosans which are found to influence the resistance of wood to attack by acid. Resistance to attack by fungi depends upon dryness, the extractives present and the hardness. In general, the darker coloured and harder woods are more resistant due mainly to the toxic dyestuffs and oils they contain. Conditions which favour fungal attack also favour insect attack. The decorative value of a wood is influenced by the structure and hardness and by the colouring matter, gums and oils it contains.

Part 4, the final article in the series, deals with the chemical utilization of wood. (Tech. Bul. F.D.C.)

Timber Harvesting and Lumber Manufacture

Stover, W. S. 1950 pulpwood production in the South. For. Surv. Release Sth. For. Exp. Sta. No. 69, 1951. pp. 26.

Gives tabulated figures showing pulpwood production by species for Alabama, Arkansas, Florida, Georgia, Louisiana, Oklahoma, Mississippi, N. and S. Carolina, Tennessee, Texas and Virginia. (For. Prod. Util. Abs.)

Ewers, J. Some negative effects of chemical treatment of pulpwood trees. Pa. For. Wat. 3 (6), 1951 (126–7).

Examination of some hundreds of trees (Red, Scarlet, Chestnut, Black, and White Oaks and Aspen) poison-girdled with Na_2HAsO_3 to facilitate barking, two months after treating, revealed little if any harmful translocation of the poison from treated to untreated stems, either by root graft or (in stem clumps) through a common root system. Examination in July 1951 of the stumps of 20 trees [species not stated] treated with Na_2HAsO_3 in July 1950 and subsequently felled, showed that the bark was alive on all trees below the treated line and that abundant sprouting had occurred on some of the smaller ones. (For. Prod. Util. Abs.)

Crawford, F. S., and Bird, J. H. Treatment of timber. Information Circular, U. S. Bureau of Mines, Washington, D. C. No. 7597, 1951. pp. 4 + 10 photos. D.S.I.R.

Describes several methods of impregnating green, standing trees, and advocates the use of chromated $ZnCl_2$, which has proved effective in the treatment of mine timbers. Much of the mine timber thus treated may be used without barking, as intact bark protects against excessive contact with the chemical. The method of treating timber in the forest is more economical as compared with operating separate timber-treating plants. The treated mine timbers can be stock-piled either in the forest or at the mine without fear of rapid deterioration. Chemicals other than chromated $ZnCl_2$ can also be used. (For. Prod. Util. Abs.)

Timber—up the hill! Timberman 53 (2), 1951 (74–80).

On tree farms of the Weyerhaeuser Timber Company in the Pacific Northwest, old-growth Douglas Fir on steep slopes is being felled uphill, by power saw, cable and winch, so reducing breakages. The ground is first cleared of larger windfalls likely to damage the trees as they are felled. A crew of 5 is used in the felling operation. A tractor with a double drum is driven on to an access road at the top of the hill, and stationed at least 200–500 ft. from the tree, with the double drum pointing towards it. A ⅝-in. cable is run downhill to the tree, and fastened by the high climber 60–80 ft. above ground level. The fellers make the undercut, on the uphill side of the tree, then the back cut, and the cable is tightened until the tree falls in the right direction. The tractor can pull several trees from the same point, and pulling distances go up to 700–800 ft. from the tractor. The crew works progressively down-hill. Safety records so far have been good, although it is estimated that danger is increased by 40%. Increased cost is offset by the market value of the timber saved. (For. Prod. Util. Abs.)

Fechner, G. H. Yellowpoplar [*Liriodendron tulipifera*] lumber grade yield recovery—a guide to improved cutting practices. J. For. 49 (12), 1951 (888–94). 12 refs. (For. Prod. Util. Abs.)

Veneer and Plywood

Crockett, G. A method of estimating the veneer yield from peeler logs. Tech. Notes For Comm. (Div. Wood Technol.) N.S.W. 5 (2), 1951 (5–9).

Gives examples of a method, based on a nomogram, for calculating yield from circular and from elliptical and buttress-sectioned logs. (For. Prod. Util. Abs.)

Brotero, F. A. Padroes de lâminas de pinho brasileiro. [Standards for laminated Parana Pine.] An. bras. Econ. flor., Inst. nac. Pinho 2 (2), 1949 (251–60). [Port. e.]

Suggested specifications applicable to *Araucaria angustifolia* and based on the standards of the [U. S.] National Hardwood Lumber Association, with definitions and suggested Portuguese equivalents of American terms relating to plywood. (For. Prod. Util. Abs.)

Ignifugation des placages. [Fireproofing of veneer.] Rapp. Fonds for. nat. Jan.–Juin 1951, 1951 (50–1). [F.] [Institut national du Bois.]

Experiments were made in the fireproofing of veneer by soaking at atmospheric pressure in an aqueous solution of "phosphate mono-ammonique" [$?(NH_4)_2HPO_4$], before making up into plywood. It was found that air-dry veneers were treated less easily than those fresh from the cutter, that speed of impregnation varied with

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Recent Publications—From page 73

Hardboard: Processes, Properties, and Potentials. P. K. Baird and S. L. Schwartz. 1952. U. S. Forest Products Laboratory, Madison 5, Wis., Report D1928. Surveys the development of the industry, properties and use requirements, raw materials, essentials of the various wet, dry, and combination processes, and summarizes production and cost figures as of today.

Weathering and Decay. U. S. Forest Products Laboratory Technical Note 221. Slightly revised October 1952.

Prevention and Control of Decay in Dwellings. U. S. Forest Products Laboratory Technical Note 251. Slightly revised October 1952.

Espave, Espavel, caracoli, Quina—by Eloise Gerry and Jeanette M. Kryn. Latest in another of the U. S. Forest Products Laboratory's Foreign Woods series.

Highlights in the History of Forest Conservation. A chronology of important events. Prepared by U. S. Forest Service. U. S. Department of Agriculture Information Bulletin No. 83. Fifteen cents from the Superintendent of Documents, Washington 25, D. C.

Forest Survey of Tennessee. Forest Survey Report. Available from State Forester, Nashville, Tenn., or from Southern Forest Experiment Station, 704 Lowich Building, New Orleans 13, La.

Standardized Working Plan for Local Tests of Seed Source. Available from the Southern Forest Experiment Station, New Orleans, La., for persons interested in starting seed test studies with the 1952 crop.

Forest Products Research Guide, Fifth Edition. National Lumber Manufacturers' Association. September 1952. This is the atlas and road guide of forest products research. The latest edition as never before pinpoints and catalogs the research and lists the various agencies that are conducting the research. The purpose of the Guide is to "catalog what has been done or is under way in many fields of research, by various firms or organizations. One of the principal reasons for publishing this Guide is to aid in the correlation of forest products research and to help prevent unnecessary duplication of research activities." Most of the Guide is given over to a carefully detailed breakdown of the major areas in which wood is the subject of research—structure, identification, and properties, processes and materials which improve or modify its properties, primary mechanical products, building, building parts, and other structures, fabricated wood products, chemicals and chemical products. In this portion of the 385-page book over 17,000 projects and programs are represented. The other half of the research picture is presented in the chapters listing in infinite detail the agencies that are carrying on or supporting research in forest products. Such agencies include colleges and universities, state and federal agencies, manufacturers, processors, consumers, and material suppliers, commercial laboratories, societies, and trade associations. An impressive list of foreign agencies is included. In all over 2,700 agencies are listed. Obviously, in cataloging forest products research in such infinite variety, the Forest Products Research Guide can make no attempt to present the *results* of research, although it does break down and show a list of pamphlets on domestic woods and indicate the agencies issuing them. Given some phase of research that is of interest to him the reader can trace it to its place in the outline and determine the extent to which various research agencies have explored the subject. Given an interest in a given research agency he can reverse the process and study its past and current research program in some detail. A feature of the Guide is a coupon arrangement for forwarding inquiries on research through N. L. M. A. The Forest Products Research Guide, a production of the N. L. M. A. Standing Committee on Products and Research, is available from the Association, 1319. 18th St. N. W., Washington 6, D. C. at $10 per copy.

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species as well as with thickness of veneer, and that saturated solutions gave much more satisfactory and rapid impregnation than weaker solutions. (For. Prod. Util. Abs.)

Glues and Gluing

Adhesives for wood. R. A. G. Knight (F.P.R.L.). Chapman and Hall Ltd., London, 1952, 242 pp., 25s.

The author emphasizes that an adhesive should be chosen according to the type of exposure and wear the finished product will experience. The various animal and synthetic glues in use are described in turn and chapters are given on the function of pressure in gluing operations, and the influence of moisture content. Notes are included on the gluing of wood "contaminated" with preservatives or with spots of paint, oil or old glue left on the surface. The influence of surface preparation is considered and reference is made to the lack of agreement as to the merits of planing, sanding or toothing the surface. Reference is also made to case-hardening and the theories proposed for explaining this phenomenon.

An outline is then given of the nature of adhesion in glued joints and the parts played by mechanical and specific adhesion. The acid or alkaline properties of glues and their influence on gluing technique are considered, and an account is given of temperature penetration into wood and temperature measurement by means of graphs or thermocouples. The method developed at Princes Risborough for measuring the permeability of glue to water is explained.

A detailed chapter on the moisture content relations of woods shows curves for moisture content in relation to humidity, including curves giving the seasonal variation of moisture content of oak, mahogany and Scots pine under different exposure conditions. Typical moisture contents are recorded for woodwork in centrally-heated offices, living rooms, and bedrooms in different parts of Great Britain. Figures are also given for average moisture contents in parts of other countries including Australia, South Africa, India and America.

The purpose and limitations of specification tests are explained and standard tests including the knife test are described. British and American methods are compared. A chapter on methods of testing by natural exposure gives details of work carried out at Princes Risborough and in Australia and India. Accelerated tests and other laboratory methods are also explained, and a classification of glues into weatherproof, weather resistant, semi-durable and interior is outlined. The bonding of wood to materials other than itself is considered and a glossary of special terms relating to glues and gluing is included. (Tech. Bul. F.D.C.)

Glossary of terms used in the plastics industry. British Standards Institution, BS 755: 1951, 59 pp. 6s.

Explanations are given of terms connected with the chemistry, industrial applications, constituents, properties and processing of plastics. In the chemical section such words as bond, polythene, alkyl resin, etc., are defined. The section on industrial applications covers terms relating to paints, e.g., oil-modified resin, ester gum, etc., and terms relating to adhesives, elastomers, laminates and moulding materials. The section on properties is subdivided into thermal, electrical and mechanical properties, viscosity, ageing and defects, and includes such terms as plastic yield, power factor, creep, shelf life, etc. Various types of presses and moulds and their component parts are explained. Terms connected with the manufacture and damage of moulds and with various moulding processes are also defined. (Tech. Bul. F.D.C.)

Panel lipping press. IMA Maschinenfabrik Klessman K. G., Germany.

A simple lipping press is provided in which pressure is applied to the edges of a panel by means of a flexible pneumatic hose. This incorporates mains-voltage resistance heating. Panels up to 7 ft. x 3 ft. x 8 in. can be accommodated. (Tech. Bul. F.D.C.)

Woodworking Equipment and Methods

Hrycyk, R. Indykator trakowy pomyslu Zakladu Mechanicznej Obróbki Drewna. [Frame-saw indicator designed in the Department of Mechanical Woodworking (of the Polish Forestry Research Institute in Cracow).] Sylwan 95 (¾), 1951 (388–96). [Pol. pol.]

Illustrated description of an apparatus designed for recording graphically the correlation of the two fundamental motions of frame-saw conversion, viz. the reciprocating motion of the saw blades and the progressive motion of the log feed. Both of these motions are transferred on an appropriate scale on to the indicator tape, where a resultant curve of both motions is obtained. This graph, it is claimed, gives a simple and unambiguous representation of the work done by the frame-saw itself as well as of the operation of the feeding mechanism, the following data being derivable: (1) average feed rate, (2) the optimum value of saw overhang for a given feed rate, (3) the degree of uniformity of feed rate, and (4) 'chip' thickness during a single stroke of the saw. (For. Prod. Util. Abs.)

Andersson, J., Schaub, C., and Simonsson, A. Ramsagblad med stukade tänder. [Frame-saw blades with swage-set teeth.] Teknish Tidskrift, Stockhold 81 (24), 1951 (513–6). [Sw.] L.S.

Results of sawing 25,600 logs showed that swage-set blades (1) gave 10% less sawdust; (2) gave straighter sawn timber; (3) had as long a working life as chromium-plated spring-set blades; and (4) gave an equally good or better timber surface. (For. Prod Util. Abs.)

Klem, G. G., and Karlsen, O. Sammenliknende skurforsok med sirkelsag blad med viggete og stukete tenner [Comparative study of sawing with circular sawblades having spring-set and swage-set teeth.] Medd. norsk tretekn. Inst. No. 2, 1951. pp. 19 + 2 photos. [Nor. e.] (Meddelelse fra Skogbrukets og Skogindustrienes Forskningsforening No. 11). P.R.

The two types of blade were compared to show (1) power consumption, (2) saw kerf, (3) accuracy of lumber thickness, (4) characteristics of sawdust and (5) the appearance of the face of sawn goods. Four gauges were used for each type of blade and a total of 180 logs of *Pinus sylvestris* sawn. Results are tabulated. (1) The swage-set blades consumed more power than the spring-set blades, but the average increase in consumption would not be significant in practice. The difference was roughly the same for low and medium feeds, but was significantly reduced for high feeds (50 m./min.). (2) There was no difference in kerf thickness between the two blades. (3) (a) On an average for all gauges, swage-set blades cut more accurately than spring-set. (b) Fine-gauge blades of both types cut less accurately than heavier gauges. (c) The decrease in accuracy obtained with the finer gauges was less for swage-set than spring-set blades. (d) For the three heaviest gauges, rate of feed did not appear to affect accuracy of sawing for either type of blade. For the finest gauge, inaccuracy in both increased with increasing feed speed. (e) For both blades, large widths were sawn less accurately than small widths. (4) The sawdust from swage-set blades appeared to be rectangular in form; that from spring-set blades to be longer and thinner. (5) There was no difference in face appearance between sawn goods from the different blades. Further research is desirable. (For. Prod. Util. Abs.)

Klem, G. G., and Seem, M. En undersokelse av skurunoyaktigheten ved forskjellige sagbrukstyper. [Research on sawing accuracy of various types of sawmills.] Medd. norsk tre-

tekn. Inst. No. 3, 1951. pp. 11 + [2] + 3 dgms., 12 gphs., 7tbls. [Nor.] P.R.

An investigation of 2,875 boards of different dimensions, produced by 34 sawmills using 6 gangsaws, 16 resaws with circular conical blades, and 16 twin circular log saws. Results showing (1) the variation in accuracy with the type of saw, and (2) the effect on timber consumption of the excess dimension allowed in sawing to ensure that all boards will be above the necessary minimum dimensions, are given in graphs and tables. (For. Prod. Util. Abs.)

Hyler, J. Special equipment speeds long handle production. Wood, Chicago 57 (1), 1952 (36). P.R.

Describes some of the latest aids for the production of long handles for shovels, rakes, hoes, etc. (For. Prod. Util. Abs.)

Wood Finishing

Roy, S. K., and Kar, B. C. Metallization and electroplating of wood, glass and plastics. J. sci. industr. Res., India 10A (6), 1951 (252–3). 4 refs. D.S.I.R. (For. Prod. Util. Abs.)

Color permanence of light finishes. Timber Engineering Company, Research Bulletin of the National Lumber Manufacturers' Association, U.S.A., Vol. 4 No. 2, 25 January 1952, p. 2.

Research into colour permanence has included a study of the effects of ultra-violet and infra-red radiation, sunlight, ordinary room light, heat, humidity and air circulation in the absence of light. Oak veneered panels in the following conditions were used: bare; stained; stained and filled; stained, filled and lacquered; stained, filled, lacquered and rubbed. A naturally light finish was used in most cases. Some panels were made with pre-bleached veneers.

Results to date show that ultra-violet light is causing the greatest darkening. Finish coatings are providing some protection, most darkening being observed on the bare, unfinished specimens. Pre-bleached finished panels have darkened slightly more than non-bleached panels coated with light finishes. Panels kept in complete darkness show no appreciable colour change, thus indicating that oxygen alone is not responsible for darkening.

It is hoped to isolate the cause or causes of darkening and then develop means of limiting its occurrence in finished furniture. (Tech. Bul. F.D.C.)

Stains in wood. Ill. Carp. Build. 141 (3881), 1952 (98). P.R.

Gives practical instructions for removing stains occurring (1) in woodwork, particularly of hardwood, near iron or other metal parts such as hinges, nails, screws, bolts, when exposed to weather and subjected to frequent wettings, and (2) in timber that has come in contact with wet concrete or mortar. Oxalic acid is recommended for the removal of the former, and HCl for the latter. (Forest Prod. Util. Abs.)

[Graham, P. H.] Here's how to apply metal coating to your wood. Wood, Chicago 57 (2), 1952 (27). P.R.

Describes the spray metallizing technique used for applying a metal coating (Al, Cu, Cd, Sn, Zn, Pb, Monel, steel, brass, bronze) to wood (Cypress, Birch, Gum, Mahogany, Oak, Redwood, Walnut). Zn is the usual primary coat metal, on top of which a metal like Cu is deposited, using the same technique. (For. Prod. Util. Abs.)

The theory and practice of finishing furniture. Industrial Finishing, U.S.A. Vol. 27, No. 12, October 1951, pp. 74–6, 78, 80, 82, 84, Vol. 28, Nos. 1–4, November 1951, pp. 76–8, 80, 82, 84, 86, 89–90, December 1951, pp. 80–2, 84, 86, 88, January 1952, pp. 68, 70, 72, 74, 76, February 1952, pp. 68, 70, 72, 74, 76–7.

An important function of a finish coating is to protect the wood by restricting the absorption or loss of moisture. Furniture finishes should also keep out any spilled water. A coating at least 0.001 in. thick is necessary to give this protection and a coat of sealer and at least one top coat are the minimum that will suffice. Both penetrating and sealing properties are necessary to give a coating which resists moisture and is mechanically tough. The use of a slow drying, slow sanding sealer and a tough filler is recommended.

Commercial bleaches suitable for furniture are usually of the 2-solution type. Transparent finishes can be used over the natural wood but stains are generally applied to enhance the colouring, to give an even tone or to provide an imitation 'grain'. The characteristics of water stains, non-grain-raising stains, spirit, oil, pigment wiping, sap, trim and shading stains are mentioned. The use of toners and glazes is also noted.

Oil dyes may be incorporated in the filler but the colours are not fast to light and may cause bleeding. A filler stain suitable for radio cabinets and novelty furniture is a synthetic type containing light-fast acid and direct dyes. Lacquer, shellac, or varnish sealers may be used and special penetrating sealers based on vinyl compounds have been developed to give good adhesion and easy sanding.

Cellulose type lacquers are widely used in finishing furniture and attempts are being made to increase the solids content of these lacquers and thus reduce the number of top coats required. Oleoresinous and urea-alkyd varnishes are also used and some of the merits of these finishes are discussed.

In the final article nine different finishing systems are outlined. (Tech. Bul. F.D.C.)

Dipping, tumbling and roller coatings for wood finishes. B. M. Letsky (A. Learner and Co.). Paint Manufacture, August 1949 (reprint).

Dipping is a suitable means of finishing parts such as dowels and chair legs. Work on the difficulty of removing the last bead has been carried out by the Ransburg Co. using an electrostatic field to draw off the bead, and a development of this method should make it possible to dip awkwardly-shaped articles. Advantages claimed for dipping are economy of materials and labour and uniformity of finish. Articles may be given a single dip in a high viscosity material followed by a slow withdrawal or they may be given quick multiple dips and withdrawals in a finish having a low viscosity but a high solids content. The chief drawback to dipping is the time required to make the jigs for holding the articles.

Tumbling is suitable for small objects and may be used to give a dry finish or a wet coating which is subsequently dried by other means. At present tumbling will not give a dry finish comparable in quality with that obtained by spraying or dipping. It is, however, a useful means of applying ground, primer, or sealer coats before dipping. Not more than 1 gallon of nitrocellulose or synthetic sealer to every 30 sq. yd. of surface should be used when tumbling to dryness.

Roller coating by the American Polyfax process enables reproductions of veneer or other textured surfaces to be made on wood, metal or plastic. Etched plates or cylinders are prepared from photographs of the surface to be copied and the pattern is then transmitted to a soft composition roller which is passed over the surface to be finished. The pattern may be protected by a lacquer finish applied by spraying, dipping or rolling. (Tech. Bul. F.D.C.)

Silicone in finishes. H. H. Connelly. Industrial Finishing, U.S.A., Vol. 28 No. 5, March 1952, pp. 72, 74, 76.

Silicones, as ingredients of finishing materials and of waxes have found a place in the furniture industry. Silicone-alkyd films have excellent resistance to heat, light, humidity and salt spray. Polishes containing silicones give a high lustre with good durability. Caution must, however, be observed in using materials containing silicones as they possess peculiarities not yet understood, and can cause serious production troubles.

Silicones should not be present in any of the undercoats, otherwise peeling or wrinkling may occur in the top coats. Further, accidental contamination of the undercoat materials by silicone-containing wiping rags may have disastrous results, and strict precautions must be taken to avoid this. When furniture has to be refinished all traces of silicone wax used in previous finishes must be removed.

Manufacturers using a silicone finish should notify the retailer of the fact, so that the repair of a damaged piece with an incompatible lacquer may not be attempted. (Tech. Bul. F.D.C.)

Seasoning and Preservation

U. S. National Bureau of Standards. Fire Protection Section. Ignition of fibrous materials by self-heating. J. Franklin Inst. 253, no. 3:259–60 (March, 1952).

Recent studies have provided conclusive proof that closely packed fibrous materials can ignite by self-heating. These materials, in quantity and after standing for some time, may develop an internal temperature higher than the surrounding one; the extent of this temperature rise will depend upon the material, its density and packing, the ambient temperature, and the length of time this state is maintained. The larger the volume of the specimen, the greater is the self-heating temperature rise within the specimen for a given ambient temperature, and the lower is the external temperature required to initiate combustion. Ignition was found to start at the geometrical center of the specimen and spread outward through the remainder of the material. The time required by different types of cellulosic materials to reach ignition varies widely. When the ambient temperature is allowed to rise with the self-heating of the specimen rather than being held constant, ignition is accelerated. Extremely large volumes of fibrous materials will ignite at relatively low ambient temperatures, so that a potential fire hazard exists in the transportation and storage of these materials, particularly after hot processing and drying. More effective control of shipping and storing temperature and of stack size is recommended. E.S. (Bul. Inst. Paper Chem.)

Wood seasoning on a small scale. J. G. Nash (Kodak Ltd., Wealdstone, Engl.). Chemistry & Industry 1952, 40-1.-A mixt. of 20% diacetone alc. in petr. ether was tested for producing wood seasoning. In this mixt. the rate of removal of water from a wooden block was roughly inversely proportional to the square of its thickness and decreased as the grain of the wood became closer. The 3/8-in. spruce took 1 hr. to dry, 3/4-in. oak 40 hrs., 1-in. maple 60 hrs., and 1½-in. apple 100 hrs. The solvent dissolved the resin in the wood and probably distributed a portion of it uniformly throughout the mass, thus dispersing local resin pockets. Warping and shaking appeared to be very small as compared with other artificial drying methods. Theresa McKee (Chem. Abs.)

Duff, M. G. Decay in wood-built boats. Ship and Boat Builder, London 5 (5), 1951 (173–7). P.R.

Summarizes the results of survey reports of 132 sea craft selected at random. Out of the 46 undecked boats examined, fungal decay was found in only 3; general decay in 4; dry wood borer in 1; marine borer *(Limnoria)* in 1. It is concluded that the general incidence of timber decay of a serious nature in open boats is very slight. Out of 86 decked boats examined, fungal decay was found in 67; general decay in 28 (of which 3 were 'severe' cases); chemical decay in 15 (1 'severe'); dry wood borer in 4 (1 'severe'); and marine borer in 17 (4 being 'severe'). It appears that ventilation is a major factor in preventing, as fresh water leakage through decks is in promoting, fungal decay; and that the preservative treatment of boat timber is in many cases impracticable. (For. Prod. Util. Abs.)

Eeckhout, L. Orienterend onderzoek naar de eigenschappen van creosoot en zijn componenten als houtbeschuttingsmiddelen. [Preliminary research on the properties of creosote and its constituents as wood preservatives.] Meded. Lab. Houttechnol., Gent No. 8, 1951. pp. 53. 100 refs. [Flem. flem. f.e.g.]

Literature on creosote is discussed, and conclusions from it on the toxicity of creosote and its fractions are summarized. Four fractions, (1) with b.p. up to 242° C., (2) b.p. 242–292°, (3) b.p. 292–342°, and (4) the residue were obtained from creosote for preserving sleepers. Fractions (2) and (3) were the most and (4) the least toxic to *Coniophora cerebella* on a culture medium. In wood-block tests, fractions (1)–(3) were very toxic, and creosote less so, while fraction (4) had practically no effect. After weathering tests (leaching and exposure to ultraviolet and infra-red rays) the heavier fractions (3) and (4) were more toxic than fractions (1) and (2). In future tests, 6 fractions with b.p. up to 210, 210–235, 235–270, 270–315, 315–355°, and the residue, will be compared, using *Polystictus versicolor* on Beech and *Lentinus lepideus* on Pine sapwood. (For. Prod. Util. Abs.)

Conservation des souches sous huile minerale. [The preservation of fungus strains in mineral oil.] Rapp. Fonds for. nat. Jan.–Juin 1951, 1951 (49). [F.] [Institut national du Bois.]

Experiments begun in 1949 have given preliminary results demonstrating the possibility of preserving strains of wood-destroying fungi in mineral oil by sub-culturing them only every 18 months or 2 years. The vigour and destructive power of the strains appear to be increased. Further experiments are being carried out with, among others, *Lentinus degener* on Beech. (For. Prod. Util. Abs.)

Findlay, W. P. K., and Vernon, J. W. A simple method for testing the toxicity of volatile antiseptics to wood-rotting fungi. Ann. appl. Biol. 38 (4), 1951 (876–80). 8 refs. [Forest Products Research Laboratory, Princes Risborough.] O.R.E.

Test fungi were cultured on a known volume (20 ml.) of filtered malt agar medium at the bottom of 500-ml., stoppered, conical flasks. When the fungus colony had reached a width of about 3 cm. its mean diameter was measured from below. The toxic chemical was dissolved in a highly volatile solvent, and 1 ml. of the solution added dropwise to 15-cm. -diam. fluted filter-paper. This was allowed to hang freely in the air for up to 1 min. to allow the solvent to evaporate, and was then introduced into the flask. The flasks were further incubated at 22° C. and the size of the colony examined after 24, 48, 72 and 96 hr. If no further growth occurred transplants were taken from the edge of the colony and placed on fresh medium, to find whether the fungus had been killed or merely inhibited. Summarized results of tests of 14 substances on 4 wood-rotting fungi are given. Such results may find application where the mycelium and spores are freely exposed, but tests with wood blocks indicated that, if infected wood of any appreciable thickness is to be sterilized, information about the penetration of the vapour across the grain of the wood, and about its sorption by the wood, must be obtained before any treating schedule can be drawn up. (For. Prod. Util. Abs.)

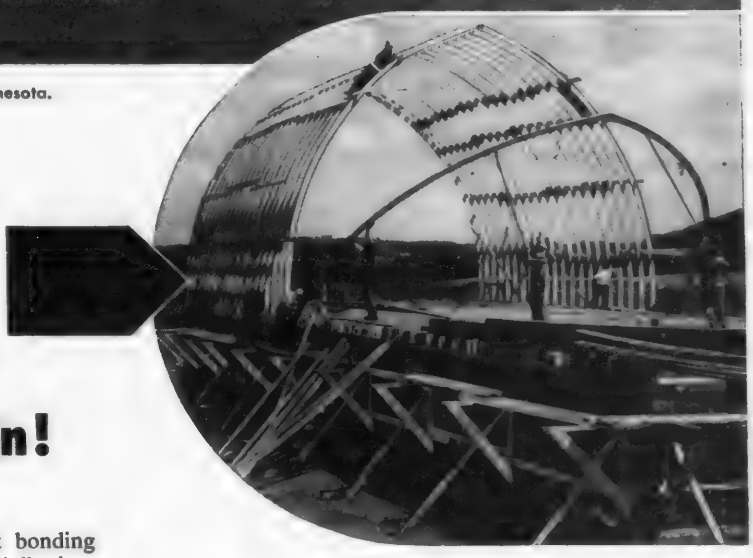
MacLean, H., and Gardner, J. A. F. Deterioration of wooden dry kilns used for drying Western Hemlock lumber. Lumberman 78 (12), 1951 (88, 90).

The Vancouver Laboratory of the Canadian Forest Products Laboratories has undertaken an investigation on the causes and control of deterioration in wooden kilns drying Western Hemlock. The kiln examined was about 6 years old, with walls of solid 6 x 6-in. Western Red Cedar and roof-boards of 2 x 6-in. Douglas Fir. The wood was badly deteriorated, black in colour and similar in structure to advanced cubical brown rot, especially round

(Continued on page 80)

Rilco chooses waterproof Penacolite® Adhesives for laminating barn rafters

Photos courtesy Rilco Laminated Products, Inc., St. Paul, Minnesota.



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metal fittings and nails, and the metal was corroded. The Douglas Fir was more seriously damaged than the Western Red Cedar. An apparatus was made to condense the vapours issuing from the roof vents of the kiln, and samples of condensate were collected during the drying of Western Hemlock and Douglas Fir. The pH of the condensate by the 4th day of a kiln run was 3.54 for Western Hemlock and 4.00 for Douglas Fir. Tests on a deteriorated roofboard showed lignin content of 61%, against 29% in sound wood. This result indicates how acid hydrolysis of the cellulose component has left a residue very rich in lignin. To confirm the conclusion that acidic conditions are responsible for the corrosion, a sample of the roofboard, cleaned down to the sound wood, along with a piece of copper and of iron wire, was exposed to an atmosphere composed of the hot vapours of a boiling mixture of dilute acetic, formic and carbonic acids (the acids identified in the condensate) at an acid concentration of pH 3.10. At the end of 3 weeks the iron wire had corroded away, the copper wire had parted where condensate had dripped on it, and the wood had darkened and showed cubical checking. It is believed that the high resin content is mainly responsible for the lack of damage during the seasoning of Douglas Fir; during a run some of the resin is distilled on to walls, pipes, etc., forming a protective layer. To prevent damage, the provision of a vapour barrier of asphalt or aluminum inside the kiln walls is suggested. Kilns of concrete-block construction should be examined periodically to ensure that the asphaltic protective coating is intact, as concrete may deteriorate slowly in the presence of dilute acids. (For. Prod. Util. Abs.)

Utilization of Low Grades and Waste

Some new European boards made from wood waste. J. Risi. Pulp & Paper Mag. Can. 52, No. 1, 82–4 (1951).—The German Lignova process and the Swiss Harder and Lignorite processes are discussed, including costs and applications of the products. The materials can be used as furniture panels and for high-grade interior finishing. C. J. West (Chem. Abs.)

Pulp and Paper Products

Stevenson, Louis T. The place of the United States paper industry in the world economy. Paper Mill News 75, No. 16:58–9, 132 (April 19, 1952).

The dominant position which is held by the United States in the world pulp and paper industry is shown by the fact that in 1950 the United States made 52% of the total world production of paper, consumed about 62% of it, and imported 59% of the total volume of paper imports. The United States also led in the production, consumption, and importation of pulp. The U. S. paper industry has been, and will continue to be an important factor in creating dollar exchange with foreign countries. However, the changes in the over-all balance of international payments are impossible to forecast. New wood-pulp capacity in North America and an increase in the consumption of domestically produced pulp by European countries may result in a greater interest in export markets by the North American industry. 2 tables. M.W. (Bul. Inst. Paper Chem.)

Chemical Utilization

Farmer, R. H., and Campbell, W. G. Chemical utilization of tropical hardwoods. Note on current work at the Forest Products Research Laboratory, Princes Risborough, England. Tappi 35, No. 4:181–3 (April, 1952).

Studies for the chemical utilization of three British Guiana hardwoods (wallaba, mora, and morabukea) are reported; the most extensive studies have been made with wallaba, although in all three cases the chemical investigation of the wood extractives is far more advanced than the study for determining the suitability of the extracted chips for fiberboard production. A dual process of utilization would determine the feasibility of exploitation of these species. 1 table, 1 figure, and 4 references. E.S. (Bul. Inst. Paper Chem.)

The aqueous hydrolysis of oakwood. A. F. Zaitseva and N. I. Nikitin. J. Applied Chem. U.S.S.R. 24, 427–38 (1951) (Engl. translation) (Russian Ed. 24 392–403).—Upon prolonged pretreatment of oakwood (Quercetum fontinale) sawdust with boiling water at 100°, the amts. of water-sol. substances obtained were: 32.0% after 500 hrs. and 65.6% after 1000 hrs.; heartwood chips gave 49.4%, and sapwood chips 52.1% after 600 hours. It was found that the various substances in wood dissolved at different rates during mild aq. hydrolysis. Thus pentosans and uronic acids dissolved fastest, lignin somewhat slower, and cellulose much slower. The data indicated that lignin exists in wood as a substance possessing its own properties and contg. a much higher percentage of C (64–66%) than the carbohydrates. The wood carbohydrates largely enter the aq. soln. in polymer form. Xylose was found to be the predominating sugar in the hydrolyzates. Anatomical investigation and microchem. reactions of cross sections have shown that the prolonged extn. with water involves intensive leaching of the wood constituents, not only in the surface layers of the cells but also in their internal portions. Measurements of the libriform cells have shown that its walls were 72% thinner after 1000 hrs. of aq. extn. than the walls of the libriform cells that had not been extd. with water. T. R. Zegree (Chem. Abs.)

Miscellaneous

Rehman, M. A., and Kishen, J. Treatment of Indian timbers for pencils. Indian For. 77 (11), 1951 (699–701). (Forest Research Institute, Dehra Dun.)

Indian species found to be suitable for the manufacture of pencil slats are Cedrus deodara, Juniperus macropoda, Cupressus torulosa, and Callitris rhomboidea. The first of these, however, has many other uses and the others are scarce, so experiments have been made with some close- and straight-grained light hardwoods, to find a treatment that would make them suitable. It was found that impregation with paraffin wax to the extent of 10–15% of the weight of the slats (treatment described) rendered Hymenodictyon excelsum, Lophopetalum wightianum, and Michelia champaca suitable. The wax was dyed red so as to give the finished product the appearance of Cedar wood. Details are given of hand tools designed at the Forest Research Institute, Dehra Dun, for the making of pencils as a home industry. (For. Prod. Util. Abs.)

Wood-worker skin diseases. Wood-Worker, Indianap. 70 (12), 1952 (51–2). P.R.

Account of a survey (by L. Schwartz, Tulipan, and Peck) on dermatitis among carpenters and cabinet-makers. Toxic and irritating wood usually affects hands and forearms only, but wood dust may affect the face and other parts of the body. Dermatitis from toxic woods resembles that from Poison Ivy. Cases of skin lesions on hands, forearms, legs, waistline and groin, caused by Mahogany woods from Brazil and Honduras, were reported. The following species have been found to be irritant to sensitive persons: Mange tree, Mahogany, Birch, Macassar wood, Pines, Spruces, Brazilian Walnut, Brazilian Rosewood, Boxwood, Satinwood, Eucalyptus, Yew, and Basswood. Moist sawdust of freshly cut surfaces is usually most dangerous. Some species, as Rungus wood, can produce severe skin trouble when in the form of old and worn furniture. (For. Prod. Util. Abs.)

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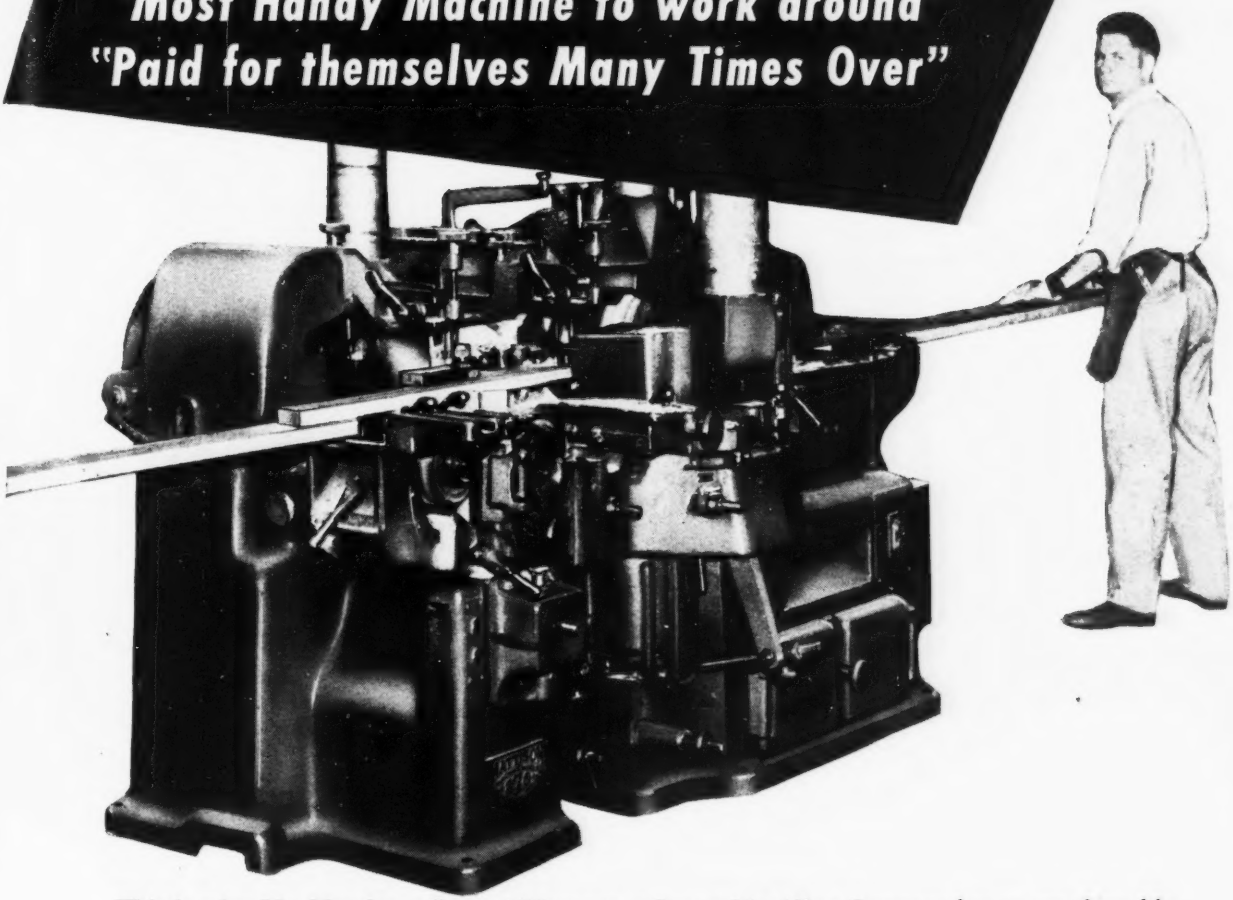

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Since this time we have experienced nothing but good results from the two Mattison Moulders which we now have in our plant. The machines have paid for themselves many times over in production alone, over our old equipment.

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Mr. Morrison says further:

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The above facts combined with the splendid cooperation we have received from your company makes the most satisfactory purchase of woodworking equipment that this company has ever experienced."

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